CONSTRUCTION TIME AND COST OF MULTI-STOREY POST-TENSIONED TIMBER STRUCTURES

A thesis submitted in partial fulfilment of the requirements for the
Degree of Master of Engineering in Construction Management (MECM)
at the University of Canterbury

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2010

Abstract

The environmentally friendly and high performance multi-storey LVL timber system developed at the University of Canterbury (UC) consisting of post-tensioned frames and shear walls is referred to as the Pres-Lam system. It is possible that this structural system has the ability to increase productivity and reduce construction costs when compared with concrete and steel construction materials. As the Pres-Lam system is a new technology, the actual construction time and cost are still unknown. The outcome of this research will add value to the construction industry and encourage the industry to consider the Pres-Lam system for future projects. Previous research has shown that construction using this type of structural system is feasible for multi-storey buildings. In case study (1), this research revisited the research done for the actual Biological Sciences building under construction at the University of Canterbury based on the latest information available from the UC timber research team. This research compared the construction time and cost of three virtual buildings (Pres-Lam, Concrete and Steel) for Case Study (1).

The research has been able to optimise the performance of the Pres-Lam system having increased open spaces with large column spacing. The proposed fully prefabricated double “T” timber concrete composite (TCC) floor system was used and found to reduce construction time. This has also shown that the LVL components in the Pres-lam system can be fully prefabricated at a factory.

In case study (1), the predicted estimated construction time for the structural system was 60 working days (12 weeks) as compared to the concrete structure which required 83 working days. In the construction time analysis only the construction time of the structural building portion was compared instead of the overall construction time of the building project. The construction cost estimation for the concrete, steel and optimised Pres-Lam overall buildings including claddings and architectural fittings were produced and compared. The construction cost analysis concluded that the construction cost of the Pres-Lam building has been estimated to be only 3.3% more than the steel building and 4.6 % more than the concrete building.

In case study (2), this research evaluated the deconstructability of the Pres-Lam system and found that the Pres-Lam system was potentially a very sustainable building material where 90% of the deconstructed materials can be recycled and reused to construct a new office building at the University of Canterbury. The reconstruction time of the STIC office building has been predicted to be 15 weeks and the estimated cost for the reconstruction to be $260,118. This will be used for future construction planning, monitoring and control.

Acknowledgements

Firstly, I would like to sincerely thank my supervisors Professor Dr. Andy Buchanan, Mr. Eric Scheepbouwer and Dr. David Carradine for the invaluable time they spent on supervision and providing guidance and knowledge throughout my research. Especially to Dr. David Carradine who assisted in proof reading, this is gratefully appreciated.

To my lovely wife (Chou Kuei Ting), without your patience, encouragement and your constant hard work to look after our three children (John, Sabrina and Reaann) during the last 18 months, the completion of this study would have been impossible.

I am grateful to the Structural Timber Innovation Company (STIC) Ltd. who provided me with a research scholarship to carry out research that hopefully in the near future will benefit and add value to our living environment.

Professional Industry Knowledge and Services provided by Graeme Jones (Arrow International Ltd.); Paul Blackler, Ross Copland, Des Allred and Lorral Eder (Mainzeal Property and Construction Ltd.); Ross Davidson and Phil Schumacher (Davis Langdon Shipston Davis Ltd.); Andrew MacGregor and Stephen Mouat (C. Lund & Son Ltd.), Thom Craig Architects Ltd., and Richard Seville and Eric McGregor (Holmes Consultancy Group) is greatly appreciated. Industry quotes provided by Terry Palmer and Paul Blundell (Construction Techniques Ltd.), Gavin Robertson (Potius Building Systems Ltd) and Mel Jackson (PSP Ltd.) are gratefully appreciated.

I would like to acknowledge the members of the UC research team, Tobias Smith, Nicolas Perez and Noryati Abd Ghafar for their contribution and especially to Michael Newcombe, who assisted in the optimisation design for the Case Study (1) building and for his invaluable time in sharing information and knowledge of the Pres-Lam system. Special appreciation to Jesus Amigo Menendez for his tutorials in Google Sketch up and David Yeoh who assisted in the TCC floor design. I also gratefully acknowledge the kindness of my officemate James O'Neill who helped on many occasions during the preparation of this research.

I wish to acknowledge the UC laboratory technical staff of Russell McConchie and Alan Poynter for their technical support during the deconstruction of the Pres-Lam experimental building. I would like to acknowledge the UC computer maintenance and services support provided by Brandon Hutchison throughout my study.

Special thanks to my mother in Malaysia, Madam Chow Fook Hoy, for her understanding and moral support throughout my postgraduate master study. Also thank you to all my relatives and friends for their moral support.

Finally, I am also grateful for the blessing and guidance received from GOD throughout my study.

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Chapter 1: Introduction

New Zealand grows trees in plantations across the country for timber, therefore structural timber is abundantly available in New Zealand. It is currently the only 100 % renewable building material available. Timber by its nature has desirable aesthetic qualities. It creates a feeling of warmth to the living environment, the colour and texture give a feeling of being close to nature. The aesthetic attraction, sustainability and durability of the timber are the driving force for building owners and architects to choose timber over alternative building materials. The manufacture of timber products is less energy consuming compared to other building materials. Using timber stores carbon for a long period of time in the building, preventing its return into the atmosphere as CO_2. Compared with concrete and steel, timber is the only carbon positive building material, as production of these other materials requires the creation of CO_2.

Timber has been used as a construction material for building houses or shelters for thousands of years. The world's oldest and tallest ancient multi-storey timber building, the Sakyamuni pagoda, is still standing in China. It was built in 1056 and is 67.3 metres high. Timber buildings in the past decades have proven their durability, but their use as a building construction material has decreased due to the increased popularity of concrete and steel materials. Concerns about global warming's impact on climate change have increased around the world, and recently the interest in and demand for sustainable (green) building materials in the construction of multi-storey timber buildings has also increased. Similarly due to recent major earthquake disasters around the world, the demand for earthquake resistant residences and commercial buildings has increased. There is a greater awareness of the importance of having an earthquake resistant building, especially in those high seismic activity zones.

Modern timber buildings have many advantages and are comparable in high structural performance and durability with other building materials. The timber engineering research team located at the University of Canterbury (UC) in New Zealand, has made a positive contribution to the development of an innovative environmentally friendly building material which exhibits high performance under seismic loads. The newly developed patented multi-storey Post-Tensioned Laminated Veneer (LVL) timber structural system referred to as Pres-Lam is gaining publicity in New Zealand and around the world. Pres-Lam is an engineered timber system which consists of post tensioning structural LVL members. This innovative structural system also exhibits ease of deconstructability that allows it to be recycled and reused.

1.1 Modern Multi-Storey Timber Buildings

The world's tallest residential multi-storey timber building "The Stadthaus" in Murray Grove Hackney, London, was completed in 2009. This nine storey building (see Figure 1a) is constructed mainly using cross laminated timber (CLT) panels produced by KLH company from Austria, has set a new world record for timber building construction. It has the highest environmental quality and lowest carbon footprint as claimed by the "Stadthaus" Architect, Mr Andrew Waugh. (Source: http://www.en.wikipedia.org/wiki/Stadthaus).

The process of manufacturing CLT involves thin timber strips glued and then laminated together with adhesives in a heated pressing process to form a solid CLT panel. Prefabricated CLT panels are much lighter and have pre-cut openings for windows and doors included which improve the overall work efficiency. Using prefabricated CLT, the overall cost of construction for the building was much the same as that of a steel and or concrete building. However, there were extensive savings of time on site as claimed by Mr Andrew Waugh.

(a)

(b)

Figure 1: (a) The world's tallest modern residential timber building "The Stadthaus", London. (b) Norway has planned to build the next world tallest wooden building. Source: (http://www.inhabitat.com/2009/08/24/worlds-tallest-wooden-building-planned-for-norway/)

The structural erection process of the building utilised a team consisting of five labourers to assemble the main structure in 9 weeks. Compared to the original estimated construction programme, it achieved an overall time saving of 22 weeks. This building, consisting of 29 apartments, was shown to be widely accepted by the public due to the speed with which it was sold (approximately 90 minutes), as claimed by Mr Andrew Waugh.

Norwegian Barents Secretariat has planned to build a 16-17 storey 80 metres high timber building in Kirkenes, Norway (see Figure 1(b)), due to the increased need for sustainable building. This building will consist of columns and beams made from glue-laminated wood (glulam) and floor components using CLT.

Recently multi-storey timber building construction in Canada has also advanced. A six storey timber building is being built in Quebec (See Figure 2(a)), the first ever building built in Canada using heavy timber frame (glulam) construction (Dubois, 2010).

On July 2009, Dr. John van de Lindt led the Colorado State University researchers in collaboration with Simpson Strong-Tie Inc. in conducting the world's largest earthquake shake table test near Miki City, Kobe, Japan. The full-scale, NEESWood Capstone seven storey wood-framed building is currently the largest wood-frame building (Figure 2(b)) ever built and when subjected to the testing equivalent of an earthquake so strong it only occurs every 2,500 years (magnitude of 7.5 measured on the Richter scale) it remained structurally undamaged.

(a)

(b)

Figure 2: (a) A six storey timber building in construction at Quebec, Canada. (b) The world's largest full-scale test model successfully tested at Miki City, near Kobe, Japan.

According to Steve Pryor from Simpson Strong-Tie Company Inc. “this experimental building was built with Performance-Based Design (PBD). By using the PBD design method, it has exceeded the minimum code requirements to help prevent structural and non-structural damage in an event of an earthquake". (http://www.strongtie.com/about/research/capstone.html). This building proved it was possible to save structures, and therefore potentially billions of dollars in a major seismic event. This can be done through initial financial investment in the careful design of the building.

1.2 The World's First Multi-Storey Pres-Lam Building

Figure 3: The World first Multi-storey Pres-Lam building, the (NMIT) Arts and media building in Nelson, New Zealand under construction, May 2010.

The Nelson Marlborough Institute of Technology (NMIT), Arts and Media Building, the first building using the Pres-Lam system in the world is currently under construction in Nelson, New Zealand (see Figure 3). The NZ Ministry of Agriculture and Forestry (MAF) has awarded $1 million to the winning team - Irving Smith Jack Architects, Aurecon, Designgroup New Zealand and Rider Levett Bucknail - towards the construction of the building. The construction of this building has revolutionised the design of future timber multi-storey buildings as claimed by Bucknail (2009) in the timber DESIGN AUSTRALASIA magazine in the winter (2009) issue. The structural design of this building uses double beams, and the wall system of this building incorporates post-tensioning technology.

1.3 Research Objectives

Time and cost are the most important elements for the construction industry's clients to selecting a construction method. The main objective of this research was to evaluate the construction time and cost of multi-storey (Pres-Lam) timber structures in comparison with concrete and steel structures. The outcome of this research will add value to the construction industry and further enable it to consider the Pres-Lam system for projects. The construction industry would benefit from the increased knowledge of this system in terms of the construction cost, time and constructability, in particular how this system compares to concrete and steel options.

The major objectives of this research are to identify:

1. **What is the construction time of Pres-Lam timber structures as compared with concrete and steel?** A faster erection process for rapid installation of Pres-Lam timber structures will be identified by collaborating with construction industry, fabricators and contractors.
2. **What are the construction costs of Pres-Lam timber structures as compared with concrete and steel?** The unit rate per cubic metre and unit rate per square metre of the Pres-Lam system will be indentified.

And to investigate

3. **How efficient is the 2 storey STIC building at the University of Canterbury in terms of deconstruction and reconstruction.** Findings will show deconstructability, time and cost of the Pres-Lam system for reconstruction.

1.4 Research Plan

The approach requires coordinating with other researchers and construction industry participants in Pres-Lam construction to collect the data and feedback regarding the latest developments of this system. Data such as the design and construction detailing, cost of fabrication, time for erection, and construction methodology were collected. Once the available initial data was collected, alternative perspectives of improvement to optimise the Pres-Lam system in the projects were studied in the form of two case studies. These are described as follows:

In Case study (1) UC Biological Sciences building, the research further improved on the research done by Smith (2008) in the "Feasibility of Multi Storey Post-Tensioned Timber Building: Detailing, Cost and Construction". Smith's previous cost estimation was based on a 'feasibility estimate' using preliminary design information of an un-built timber structure compared to a 6 storey concrete (the UC Biological Sciences) building under construction**.** Due to the lack of information about the construction time and cost of the Pres-Lam system at that time, the comparisons carried out by Smith (2008) on construction time and cost estimation were based on educated assumptions. He suggested various methods for optimising the structural performance of Pres-Lam system. Present research used a better and more accurate analysis (e.g. materials, design, equipment, constructability and labour for all items of related work) of construction cost estimation because of the available data and references from the completed 2/3 scale Pres-Lam experimental building at UC. This research revisited the earlier work and identified specific areas for improvement. This was done by incorporating insights from the designers, fabricators, and contractors.

Case study (2) Deconstruction and Reconstruction of the STIC building at UC.

Part (1) of this Case Study (2) was to evaluate the deconstruction of the completed Pres-Lam experimental building in terms of deconstructability, time, cost and other potential construction problems. Deconstructability is often over looked in construction. A sustainable construction material must be able to be dismantled after use in the first life cycle and reused for other purposes multiple times before the end of useful life. Hence it is essential that the deconstructability of the Pres-lam system be investigated. After deconstruction, the 2/3 scale experimental Pres-Lam building will be reused and become the Structural Timber Innovation Company (STIC) office, relocated to an open space near the Physical Sciences library at the University of Canterbury. This new STIC office building will showcase to the public the advantages of the latest innovative timber technology.

Part (2) of this Case Study (2) investigated the reconstruction in terms of how rapidly the prefabricated Pres-Lam components can be reassembled. The time and cost of the reconstruction of the STIC office building has been investigated. This part of the research required collaborating with industry, such as the designers, to obtain drawings and specification related to the proposed project. Unfortunately the reconstruction had not occurred at the submission time for this thesis, so the reconstruction time and cost are estimated.

Note:

This research compared the construction cost of three virtual buildings (Pres-Lam, Concrete and Steel) for Case Study (1). Structural design was not included in this research. The optimising of the structural design for Case Study (1) was conducted by other researchers (Michael Newcombe and David Yeoh). Architectural and structural drawings are available and minor amendments to the drawings and detailing sketching were produced for this research.

1.5 Organisation of the Thesis

Chapter 1 is an introductory chapter describing the background multi-storey timber buildings construction, and setting the objectives.

Chapter 2 consists of a literature review describing the background, summarising the research work done, covering the development of the Pres-Lam system and presents the overviews of the manufacturers and the fabricators of laminated veneer lumber (LVL) structures.

Chapter 3 describes the lessons learned from the 2/3 scale experimental Pres-Lam building, by UC researchers, and the participants from the construction industry.

Chapter 4 provides the background of the Case Study (1) building, and describes the simplified version of the concrete building, presents an overview of the optimised seismic frame design and the design for fully prefabricated double "T" floor system for the Pres-Lam timber building.

Chapter 5 investigates three different types of floor systems, presenting an overview of the semi-prefabricated TCC floor system developed at the University of Canterbury, the availability of alternative such as the Potius floor system, and the selection of the proposed fully prefabricated TCC floor system used in the Case Study (1) building.

Chapter 6 presents the construction method used and describes the erection sequence for the Case Study (1) optimised timber building. It also covers the connection details used in the optimised timber building.

Chapter 7 presents a breakdown of the erection time for each component in the Case Study (1) optimised timber building that has led to the developed construction programme (Gantt chart). The construction programme for concrete was produced for comparison. Field interviews were conducted with the related construction industry professionals (project manager) to determine the construction sequence and construction programmes.

Chapter 8 covers the detailed construction cost analysis of the Case Study (1) buildings. The delivered and in place cost for the Pres-Lam system in terms of the unit rate per cubic metre and unit rate per square metre are indentified. Detailed construction cost estimation for Case Study (1) buildings were analysed. Field interviews with the related construction industry professionals (quantity surveyor) to determine the construction cost estimations are described.

Chapter 9 shows the Case Study (2) deconstruction process of the experimental building and describes the deconstruction time and cost analysis. The lessons learned from the deconstruction were recorded for future building projects.

Chapter 10 covers the Case Study (2) construction management project planning and identifies the projected construction time and cost for the proposed reconstruction of the STIC office building at the University of Canterbury.

Chapter 11 concludes this report by presenting the advantages and disadvantages of the Pres-Lam system and explaining how the research objections have been achieved.

Chapter 2: Literature Review

Published literature on the time and cost for the construction of multi-storey post-tensioned LVL buildings is limited because it is a newly developed innovative engineered system. However, there is literature about post-tensioned LVL in terms of the development, design, testing, sustainability and fire resistance that needs to be understood before the evaluation of construction time and cost can be investigated.

Smith (2008) was the first researcher to look at the feasibility, design and cost of construction of this system. In his report, he made a comparison of a six storey post-tensioned timber building and a comparable concrete and steel building. These designs were simplified versions of the actual six storey Biological Sciences concrete building currently under construction (2008-2010) at the University of Canterbury. He reported that it is feasible to construct multi-storey buildings using post-tensioned timber engineered building materials. He concluded that the construction cost of post-tensioned timber building is about 6.5% higher than the concrete and steel buildings, and the construction time is similar to both the concrete and steel structures.

Subsequent research was conducted by Menendez (2010). He completed research on the feasibility of multi-storey Pres-Lam timber buildings in terms of design and construction. He carried out a case study of a three storey hotel project in Napier, New Zealand and concluded that currently the cost of Pres-Lam structure is 5% more than the concrete-steel structure (Menendez, 2010). In terms of construction time, the Pres-Lam system is three times the faster than a concrete frame and 50% faster than a steel frame (Menendez, 2010).

Newcombe et al. (2010) recently presented a paper for the World Conference for Timber Engineering (WCTE) 2010 on the design, fabrication and assembly of a two storey post-tensioned building which provided references for the latest information about the cost and time of the Pres-Lam system. Chapter 3 of the thesis will further describe the literature review about the latest findings of the Pres-Lam system.

2.1 Light Timber Frame Multi-Storey Buildings

In the past decades structural timber for multi-storey buildings was not a desirable material due to problems related to fire resistance, floor vibration and acoustic performance. Recently, solutions to these problems have been developed and the construction of multi-storey timber building has increased (Jorissen et al., 2008). The construction of multi-storey buildings made from timber or engineered timber products is gradually becoming more popular, even in many densely populated cities in Europe, Canada, USA and Japan, where concrete or steel alternatives are more expensive to construct. The main reason is that timber is one of the most environmentally friendly (having a low carbon footprint) structural materials as compared with concrete and steel according to Buchanan (2006), Perez et al., (2008) and John et al., (2009).

Many countries around the world have limitations of building heights imposed by the building codes restricting how high a timber building can be built due to concerns about fire resistance and acoustic separation. British Columbia, Canada has recently allowed up 5 to 6 storeys (Skulsky, 2008); USA has allowed 4 to 5 storeys (Cheung, 2000), Japan has increased from 3 to 5 storeys, Australia allows up to 3 storeys, UK has recently allowed up to 8 storeys high (Caulfield, 2009), Sweden allow up to 4 storeys and in other European countries such as Austria and Norway building regulations allow timber buildings more than 6 storeys high. In New Zealand there is no building code restriction on the height of a timber building (Banks, 1999) and (Canada Wood Council, 2008). In 2005, a six level timber framed apartment building was built in Wellington (Milburn, 2005), and this is the highest timber framed buildings constructed in the highest seismic zone in the country. In Sweden (Walford, 2006) and many countries around the world, multi-storey timber framed residential buildings have proven to be much more cost effective and faster to construct as compared with concrete or steel alternatives. Most of these buildings are built using light timber framing or larger numbers of structural wall panels, internally and externally, for bracing in order to achieve the necessary structural performance of the building.

Modern commercial structures, such as office buildings require a more open plan design for better manoeuvrability. This can be achieved by having larger spacing between columns (Figure 4). Cross laminated timber panels (CLT) developed in Austria and Europe utilise large pre-fabricated tilt-up walls that can be used as load bearing walls, roofs and floors and are suitable for residential and commercial buildings where the internal wall panels serve as the overall bracing to the building. These are unsuitable for open plan office building due to the main disadvantage of CLT, the panels in that they do not have enough compression strength to allow them to be post-tensioned (Smith, 2009). The rigidity of the design when using CLT panels has the disadvantage that it does not allow changes to floor layout because walls cannot be removed for future renovations and the limitations in the size of the wall panels (up to 2.95 metres wide and 16.5 metres long).

Figure 4: Open plan office building with large laminated timber columns spacing (Reproduced from Kolb, 2008).

The Pres-Lam structural system developed at the University of Canterbury can be applied to achieve open plan structures. This enables a more extensive use of engineered timber products in large buildings, providing better living and working environments as well as ensuring a structurally sound building that is very resistant to natural disasters like earthquakes, fires and extreme weather (Buchanan et al., 2008).

2.1 Background for the Development of Pres-Lam

At the University of Canterbury research into the development of a high performance Pres-Lam system has intensified since the beginning of 2005. Several tests have been conducted on structural members (column, beam, shear walls, and TCC floors), beam-column connections, column to foundation connections, fixings and many others aspects which have provided reliable confirmation of the seismic performance of the Pres-Lam system. Previous and recent research done at the University of Canterbury also included: investigation on LVL seismic resistant wall (Palermo et al., 2006a), and frame subassemblies and Quasi-static cyclic tests on seismic-resistant beam-to-column and column to foundation subassemblies using LVL, (Palermo et al., 2006b); emerging solutions for high seismic performance of Precast/Prestressed Concrete Buildings (Pampanin et al., 2005); Multi-storey Prestressed Timber Buildings in New Zealand (Buchanan et al., 2008), non-conventional multi-storey Timber Building using Post-Tensioning (Buchanan et al., 2009); improved seismic performance of LVL Post-Tensioned walls coupled with UFP devices (Iqbal et al., 2007); Seismic resisting structural systems using Laminated Veneer Lumber (Newcombe, 2005); Seismic design and numerical validation of post-tensioned timber frames (Newcombe et al., 2008); Design, fabrication and assembly of a two-storey post-tensioned Timber Building (Newcombe, 2010); feasibility, design, construction cost and time of multi-Storey Post-Tensioned Timber Buildings (Smith, 2008); Construction time and cost for post-tensioned timber buildings (Smith, 2009); and Investigation of short term and long term behaviour of the semi-prefabricated LVL-Concrete composite floor System for the Australasia market (Yeoh et al., 2008, 2009, 2010).

Pres-Lam is an engineered timber system which consists of post tensioned structural LVL members. The Pres-Lam building system is a technology based on an adaption from the recently developed post-tensioned precast concrete movement resisting frames and shear wall construction in the U.S. known as the PRESSS (Precast Seismic Structural Systems) Program at the University of California, San Diego (Priestly et al., 2007).

The PRESSS Program developed the hybrid connection, a technique that combined post-tensioned and reinforced concrete and inspired the UC research team to develop the present Pres-Lam system. As the research in this newly developed LVL system intensified at the University of Canterbury, the Structural Timber Innovation Company (STIC) was established in 2008 to research and implement this post tensioned LVL technology in New Zealand and Australia. STIC is a research consortium funded by the Australia and New Zealand major timber industries, governments and leading research organisations that aims to promote the greater used of post-tensioning timber products (especially LVL and glulam) in the construction industry. STIC has a total investment funding of $10 million for 5 years from 2008 to 2013. The research is mainly targeted on the technology advancement of timber structural products used in larger span and multi-storey commercial buildings.

The development of this sustainable timber engineering system is in line with the New Zealand Government's call for the construction industry to build more sustainable buildings, use renewable materials and reduce carbon dioxide emissions**.** It is possible that this Pres-Lam structural system has the ability to increase productivity and reduce construction costs when compared with the alternative construction materials. This innovative timber system is an excellent example of how the New Zealand timber sector can work together to produce world class timber engineered products that will add value to local timber products and also create jobs for New Zealand. However, in general, the public has the perception of timber as being not durable, combustible, low-tech, and not a suitable material for multi-storey building construction (Jorissen et al., 2008). With the development of engineered timber products, this is now possible. A short description about how the LVL is manufactured, fabricated, and NZ current LVL producers and LVL fabricators will be described in the next section.

2.2 Laminated Veneer Lumber (LVL) Structural Components

Laminated veneer lumber (LVL) is an engineered timber product. The process of manufacturing LVL in New Zealand utilises the Radiata Pine wood species, which involves peeled veneers (3mm in thickness) laminated together with resorcinol adhesives in a heated continuous pressing process to form a solid LVL billet (section). The billet can vary in size between 12mm and 120mm thick but the most commonly available sizes are 36mm, 45mm, 63mm and 90mm and are produced to a width of 1200mm. The current maximum length is 15 m which is due to commercial transportation limitations. This manufacturing process serves to minimise weakness in the timber as the veneers are glued together in a parallel configuration, thus creating a higher strength engineered wood product.

There are two LVL suppliers available in New Zealand: Carter Holt Harvey in the North Island and Nelson Pine in Nelson on the South Island. LVL can be used in many applications either in short or long spans structures. During the prefabrication process, the LVL billets are customised to any prefabricated component sizes such as beams, columns, floor joists and walls depending on client requirements. The beams and walls can be fabricated with full-length cavities to allow for placement the post-tensioning tendons.

Currently there are only a few timber fabricators in New Zealand producing structural components. Their main activities are still in glulam fabrications and most of these are handmade. Three main fabricators are McIntosh Timber Laminates Ltd. (North Island), Timberbond industries Ltd. (North Island) and Hunter Laminates Ltd. (South Island). Craftbuilt Industries Ltd is a much smaller glulam fabricator located in Levin, North Island. The manufacturing process currently used by these fabricators has not been automated.

There are many advantages in increasing the use of prefabrication of LVL timber components. Such advantages are the working time on building site, cost efficiency and attaining better quality control during construction and fabrication. The current economic crisis and the competitiveness of the construction industry have made it difficult for this innovative system to penetrate into the market. While other industries, such as the manufacturing industry, react to changes rapidly, the construction industry tends to be conservative and practical. Procurement of a new building project is, in most cases, based on cost. Recently, in selecting a project, the building owners have placed high importance on these four factors: the time required, construction cost, the sustainability of the building and the possible risk associated with the construction. Therefore, it is of high value to investigate the cost and time factors for this engineering system.

2.3 Summary

Previous research done by Smith (2008) has shown that the construction of this type of structural system is feasible for multi-storey building construction. There are many advantages in increasing the use of prefabrication of LVL timber components. Pres-Lam is an engineered timber system which consists of post tensioned structural LVL members. The Pres-Lam building system is a technology based on an adoption from the PRESSS program. The Pres-Lam structural system is also intended to use for open plan structures, this structural system is a new technology, and the actual construction time and cost are still unknown. Therefore, it is of high value to investigate the cost and time factors for this engineering system.

Chapter 3: Lessons learned from the 2/3 scale experimental building

In 2009, a Pres-Lam experimental building 2/3 scale was constructed and tested (Newcombe, 2010) at the University of Canterbury (UC), Civil Engineering structural laboratory (See Figure 5). The completed testing and analysis of the experimental building has generated data and information. This can be utilised for future Pres-Lam buildings. The information acquired from the testing included: constructability of the LVL, feedback from fabricators and contractors, construction time and cost, health and safety issues, earthquake performance, beam-column connection details, composite floor system and the vibration performance of the floor system. The experimental building has provided better and more accurately detailed information for the construction time and cost analysis.

Figure 5:-The 2/3 scale experimental building was successfully tested at University of Canterbury.

Most of the data and information from the experimental building were from Newcombe (2010). Other related data are from literature reviews containing the knowledge of other timber researchers at UC, and from the feedback received from the construction industry participants such as fabricators and contractors.

3.1 Earthquake Performance

The Pres-Lam system performed very well under simulated in earthquake motions (Newcombe, 2010). The building has been through over 30 earthquakes tested to initial 2.5% drift and finally tested up to 3% drift (equivalent to approximately 8.5 measured on the Richter scale) and it returned to its original position without any structural damage, and was still standing with very minor hair line cracks in the floors. The combination of PRESSS hybrid design and the benefits of LVL engineered wood products that have high and consistent characteristic strength values and are excellent for load bearing structures, has lead to the exceptional structural performance of the Pres-Lam system (Newcombe, 2010).

3.2 Dimension, Sizes and Straightness

LVL can be used in many applications including short and long span structures. LVL components can be easily customised to any dimension and size as to the client requirements. In order to utilise the LVL effectively, designers should be aware that when choosing a member size, fewer layers of LVL laminates will provide a cost reduction during fabrication. For example, a cross sectional beam of 378mm wide will have 6 layers of 63mm LVL laminated, while the 396mm wide beam have only 5 layers comprising of 2 x 63mm and 3 x 90mm LVL laminates, and will cost less.

LVL components do not twist or warp nearly as much as solid timber members. According to Newcombe (2010), in terms of straightness, LVL components can be fabricated to very strict accuracy in dimension and tolerance specification ($\pm$2mm) which is not normal practice in concrete or steel construction.

3.3 Constructability of Pres-Lam System

Mainzeal, the general contractor and erectors of the experimental building, commented that the Pres-Lam system speed of assembly was very fast compared to other building materials. Initially they had planned to complete the experimental building in five working days but they actually only needed two working days with four workers (Newcombe, 2010) to erect the building. Moreover, even though some of the prefabricated elements were delayed in delivery to site for a day, this did not hinder the construction time due to ease of movement and simplicity of the prefabricated LVL components which allowed flexibility to handle changes in construction sequence (Newcombe , 2010).

Prefabricated Pres-Lam components are relatively light, and therefore easy to handle during transportation and erection. A much smaller mobile crane and smaller design foundations are required when compared with a concrete building. According to the contractor (Mainzeal), bracing can be easily fixed to Pres-Lam components and the amount of temporary bracing required is less than concrete buildings. Precast concrete buildings normally require lifting hooks or temporary insert plates specially designed and cast into the precast components. Avoiding these also has significant savings in the construction costs of the Pres-Lam system.

However, the complicated and labour intensive fabrication for the LVL members (column to beam connections and floor units) should be avoided. The details of these problems will be discussed in Sections 3.5 and 3.11.

In terms of deconstructability, prefabricated Pres-Lam timber buildings have the advantage that they can be disassembled and reconstructed elsewhere at the end of their used life, or components can be recycled for other uses (Buchanan et al., 2008). Case Study (2), Chapter 9 and Chapter 10 of this research will investigate these possibilities.

3.4 Feedback from LVL Fabricators and Contractors

Hunter Laminates Ltd. and McIntosh Laminates Ltd. (Glulam fabricators) suggested that the high labour cost to cut notches on the plywood and on the LVL floor joists, and then later seal the bottom gaps for the semi-prefabricated TCC floor panel should be avoided. This problem can be solved by replacing the cut notches with just 2 x 45 ºinclined couch screws (M10 $\times$130 mm long) that also give the same strength and thus gave huge cost reduction suggested by Michael Newcombe.

According to Mainzeal, the system is so light, easy and safe to work with compared to others building materials. The light weight of TCC floor panels allowed the installation to be carried out manually without the use of a crane. Other advantages of the floor panels are that they served as an immediate working platform and under floor propping was not required.

Post-tensioned specialist company (Construction Techniques Ltd.) commented that there were no significant differences in the post-tensioning works between the commonly used concrete buildings and the Pres-Lam building. According to Newcombe (2010) the post-tensioning works was completed in 2 hours.

The project manager for the LVL building in Nelson (NMIT Arts and Media building) Arrow International Ltd commented that:

1. Current manufacturing process for LVL is very labour intensive, the time required to fabricate LVL components is much longer as compared to precast concrete.
2. Due to the size of the current LVL fabricators, they do not have sufficient covered storage space to store the completed prefabrication components prior to delivery on site. Clients and contractors involved need to provide a covered storage space for the prefabricated LVL components and this will have extra cost implications to the project.

3.5 Fire Resistance

According to Buchanan et al., (2009), LVL components have been tested and have satisfied the NZ fire protection safety requirements. A sprinklered timber building will have the equivalent fire safety performance when compared with other building materials. How a building performs in fire is not purely based on the materials used but is rather based on how the building is designed and constructed. Research looking at the fire performance of semi-prefabricated "M" section LVL concrete composite floors (O'Neill, 2009) found that they performed well under fire conditions, with generic floor sizes lasting in excess of an hour under scaled loads. Buchanan et al., (2008) suggested that the fire rating of the floor system in multi-storey timber buildings can be further improved by using fire-rated suspended ceiling materials. O'Neill (2009) highlighted an important observation that the separation of the double beams expedited the charring rates of the floor system. This is due to number, type and spacing of the mechanical fasteners used to hold the double beams together. He suggested that in order to avoid separation, the double beams can be fully glued together or use threaded fasteners with close spacing. Further research to investigate the problem is running parallel to this research and is ongoing at the University of Canterbury.

3.6 Occupation, Health and Safety Issues (OH&S)

The Pres-Lam components are much lighter than concrete and steel. Therefore they are easy to handle during transportation and erect by crane, reducing the risk of injury onsite. During the assembly of the 2/3 scale experimental building, temporary timber handrails were easily screwed to the LVL components to improve the on-site safety (Newcombe, 2010). Pres-Lam components are fully prefabricated off-site generating less noise and waste during construction. In addition during construction LVL components do not produce or release any harmful airborne dust, hence improved overall onsite OH&S conditions.

3.7 Properties, Durability and Appearance

The properties of the LVL components used must have a modulus of elasticity between 10 to 11 GPa, and the moisture content should be around 12 to 15%. Prefabricated LVL components are not treated for insect and fungi attack therefore but must be wrapped with plastic sheets to avoid extreme weather during transportation. The prefabricated LVL components must have a layer of protective surface coating that can last for three months and designed to provide temporary weather protection during construction. Buchanan et al., (2008) commented that timber buildings can last for a long time if protection is provided to ensure that the timber building can withstand fungal attack, insects and fire. Good timber design and construction practices are essential to ensure that the LVL components are kept away from high moisture content and insect attack. Only water-tight external cladding shall be used for buildings using the Pres-Lam system.

When glass is used as the external cladding, the naturally aesthetic beauty of the skeleton of Pres-Lam structural system can be exposed. Exposed suspended floor structures also create an important architectural feature. Generally when aesthetics are an important design consideration, exposed sawn timbers, glulam members or LVL components are often used. This has been commented on by many local architects who have seen or experienced the 2/3 scale experimental building. The world's first Pres-Lam (NMIT) Arts and Media building project under construction in Nelson, was designed according to this key concept.

The Pres-Lam system uses unbonded post-tensioning tendons. To ensure the durability of the post-tensioning system, the Post-Tensioning Manual (2006), published by the Post-Tensioning Institute suggested that standard unbonded tendons rely heavily on a multiple barrier system. First is from the component itself, in this case the LVL to avoid corrosion. Secondly, sheathing is used to protect the strand, followed by post-tensioned grease coating. Extra care must be taken to avoid breach of sheathing during handling and placement so that the tendon is well protected. The anchorage zone requires extra protection, and fully encapsulating the tendons will provide excellent corrosion resistance for durability and low maintenance of the system. Encapsulated systems are designed to provide a tendon that is watertight from end to end. During the service life of the post-tensioned structures inspections should be carried out on a periodic basis to assess the need for any preventative maintenance. Therefore it is essential that the design of the post-tensioning system used in the Pres-Lam system should take this into consideration.

3.8 Acoustic and Vibration Performance

The floor system used in the building must meet the target values of 55dB STC (minimum airborne value) and 58 dB IIC (maximum impact value) according to Eurocode 5 (1995). To design for high standards of sound insulation in a floor system, the mass per unit area (kg/m^2) was considered to govern the design (Kolb, 2008). To achieve these requirements, a concrete slab or topping is normally used to increase the acoustic mass and a suspended ceiling can be used. Based on European practice, the floor sound isolation was accomplished by applying multiple layers of different materials such as 25.4 mm thick gypsum based underlayment over the plywood sheathing and the LVL joists. If necessary the ceiling can be used to improve the acoustic separation between floors.

In terms of vibration performance, AS/NZS 1170.0:2002 and Eurocode 5 (EN 1995-1-1: 2004) limit the fundamental natural frequency to 8 Hz for the lower frequency residential timber floors. Recent investigations by PhD researcher Noryati Abd Ghafar on the performance of floor vibration for the timber floor system of the 2/3 scale experimental building concluded that the floor system satisfied the above vibration performance requirement.

3.9 Sustainability

In term of sustainability (Perez et al., 2008) a recently published paper has investigated four types of buildings (concrete, steel, timber and timber plus) based on the same Case study (1) Biological Sciences building currently under construction at the University of Canterbury. His findings concluded that the timber-plus building has the lowest total life cycle energy consumption and lowest total life-cycle CO_2 emission while the steel building had the highest impact in both categories. The 'timber-plus' building is similar to the LVL timber building in structural system, which has increased the use of timber throughout the building from the cedar windows and louvers, to timber ceiling, solid timber internal walls and external timber wall cladding.

Subsequently a similar research report was produced by John et. al. (2008) under contract with the NZ Ministry of Agricultural and Forestry (MAF) which investigated the "*Environmental Impacts of Multi-Story Buildings Using Different Construction Materials"* which concluded that the increases in the amount of timber used in large-scale commercial buildings can decrease some environmental impacts of the building. Four types of buildings (concrete, steel, timber and 'timber-plus') were evaluated, and results indicated that of the 'timber-plus' building had the lowest net environmental impact, producing 4571 tonnes CO_2 equivalent while the steel building had the highest net impact producing 6,789 tonnes of CO_2 equivalent. This 'timber-plus' building is estimated to have saved 2056 tonnes to 2218 tonnes of CO_2 emission as compared with a concrete and steel building, respectively. The demand of Forest Stewardship Council (FSC) certified woods products is increasingly becoming common in the building industry to achieve Green Star Ratings. LVL manufactured from CHH and Nelson-pine is indeed FSC certified.

3.10 Construction Costs for UC Experimental Building

Details about the construction cost related information of the 2/3 scale experimental building was extracted from (Newcombe, 2010). Here are some facts about the building:

- The total cost of the 2/3 scale experimental building was $70,139, and excluded the cost of foundation for the building. Materials and off-site prefabrication (delivered cost) contributed 78% to the total cost.
- To assemble the Pres-Lam system contributed 14%, post-tensioning work 2.6% and the in-situ concrete slab 4.6% respectively.
- The delivered cost of the building can further be broken down into the structural components: Structural frame (55%), wall system (17%), floors (23%) and transportation (3.4%). The labour cost for off-site fabrication contributed 28% of the total cost of the delivered cost of the building.
- However, this cost is expected to gradually reduce as the LVL fabricator will have better understanding and improve the manufacturing process of Pres-Lam system.
- Newcombe (2010) highlighted some interesting findings, the test model used internal steel plates for the beam-column joints and the semi-prefabricated TCC floor units, both were very complicated detailing that was very labour intensive during fabrication. The labour costs for the floor units contributed 10% to the total cost of the delivered cost of the building.
- The floor system is the most uneconomical system in the building equal to \$206/ m^2. The costs are broken down to fabricate the floor panel equal to \$162/m^2 plus another \$44/ m^2 for the cost of in-situ concrete slab. The equivalent precast concrete double tee floor systems of 2400mm wide cost around \$85/m^2 to \$95/m^2 (Rawlinson's, 2009).
- The cost for basic frame (delivered and in place) for the 2/3 scale experimental building was \$3450/m^3 and the wall system (delivered and in place) inclusive of the edge beams was \$3953/m^3. Although the wall system cost more per cubic metre, it was more cost effective than seismic frames for resisting lateral loads. The wall system which resists the same lateral loads with the seismic frame was only 17% of the delivered cost and it utilised less LVL in volume. For further details, refer to Newcombe (2010).

The construction costs from the 2/3 scale experimental building should not be used directly for costing future Pres-Lam buildings. These construction costs should just serve as a reference because this building is a test model that had incorporated many complicated beam-column details in a single building aimed at investigating the different structural performance of each system. The total floor area for this 2/3 scale experimental building was relatively small, and the total LVL volume used was relatively low as compared with high labour content (Newcombe, 2010) used to fabricate the Pres-Lam structure.

3.11 Summary

Based on the above information acquired, the experimental building has providing better and more accurately detailed information for the construction time and cost analysis. A large amount of other important data from which lessons can be learned also has been generated, and this can then be used for future Pres-Lam buildings. In summary, the advantages by using Pres-Lam system as the alternative choice of multi-story building material are as follows:

- In terms of strength, the Pres-Lam structural system was tested and satisfies the current New Zealand earthquake building code as a good seismic performance building material.
- In terms of constructability, the Pres-Lam system is light weight and has easy manoeuvrability. Therefore it is easier for transportation, requires a smaller foundation, and a smaller crane for installation.
- In terms of sustainability, the Pres-Lam system is currently the only 100 percent renewable building material available and currently is the lowest carbon footprint building material available.
- In terms of occupational health and safety**,** the Pres-Lam system is prefabricated off-site and generates less noise. Prefabricated LVL components have the advantages of cost control, waste reduction, better quality, reduction of construction time and lesser dependency on weather. It has the overall possibilities to maximise construction efficiency and improve performance for construction of multi-storey buildings.

Chapter 4: Case study (1) Biological Sciences Building

4.1 Introduction

Previous research done by Smith (2008) has proven that using the Pres-Lam structural system is feasible for multi-storey building construction. Smith (2008) used the Biological Sciences building for the case study. He compared three different types of buildings (concrete, steel and LVL timber). This research revisited the research done by Smith (2008) for the Biological Sciences buildings updated with the latest information available from the UC timber research team and incorporated insights from the designers, fabricators, and contractors to identify and rectify specific areas for improvement. This research compared the construction time and cost of three virtual buildings (Pres-Lam, Concrete and Steel) for Case Study (1). Architectural external and internal fit-outs would not be considered for all three buildings in Case Study (1). The following sections will describe the case study buildings in detailed.

4.2 The Background of the Actual Case Study (1) Concrete Building

The actual six storey building is currently under construction (2008-2010) at the University of Canterbury and has a gross floor area of 4,300 square metres for use by the Biological Sciences Department (Figure 6). The six storey main building is approximately 36 metres by 20 metres. The building structure is designed according to the latest New Zealand building codes. Lateral and seismic loads of the building are resisted by movement resisting frames in the long (east-west) direction, and concrete shear walls in the short (north-south) direction.

Figure 6: The actual Biological sciences building under construction at the University of Canterbury (photo taken on March 2010).

The structural members of the actual building have been optimised for off-site prefabrication. The shear wall panels are 310 mm in thickness and consist of a 200mm thick concrete tilt up slab that incorporates 110mm insulated infill. This is an energy efficient precast concrete product which is referred to as “Thermomass”. These types of wall panels also serve as the finishing cladding to the building. The movement resistant seismic concrete frames are an “H”-shape precast concrete frame consisting of columns and beams (See Figure 7 below). Columns are spliced at every mid storey height of each floor of the building, and beams are connected by in-situ concrete joints. The floor system utilises two types of precast long span hollow core panels spanning the north-south direction, with a thickness of 200mm and 300mm respectively, finished off with in-situ 90mm concrete toppings. This building also incorporates precast staircases and precast lift cores.

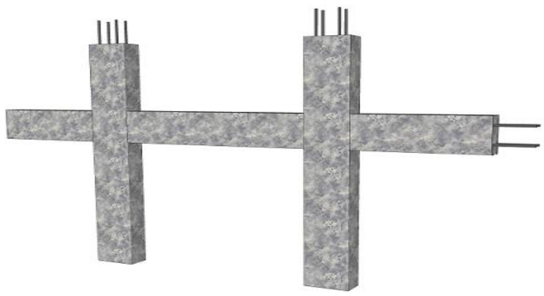
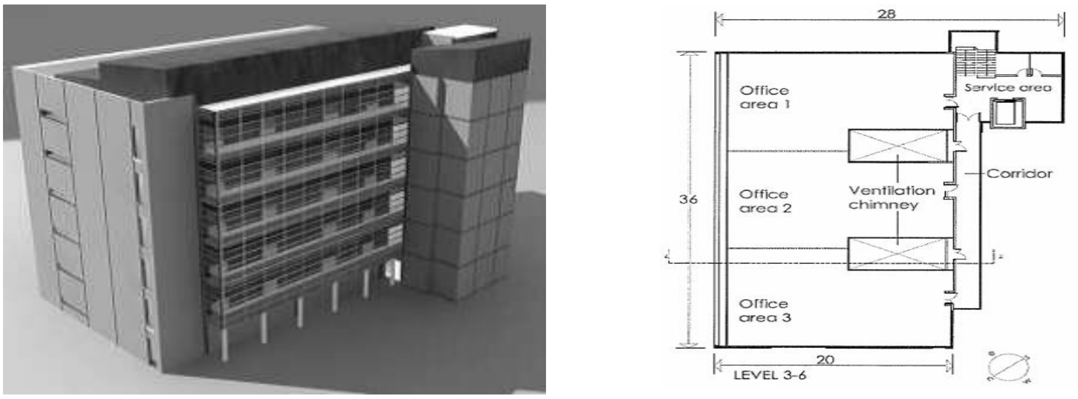


Figure 7 : An “H” shape Precast Concrete frame

4.3 The Simplified Concrete Version

An architectural impression of the simplified concrete “virtual” building is shown in Figure 8 (a).The original design of the Biological Sciences building was very complex, it consisted of various research laboratory rooms: special cold storage rooms and chemical storage rooms (see Figure 9). The basement level consisted of sea water storage tanks and other complex layouts where some minor changes to the original concrete building, especially at basement level, were necessary. The entire basement level (concrete box) and the atrium link way to the adjacent building have been removed in the simplified version. Lateral and seismic loads of the building are resisted by three precast concrete frames and the walls to resist lateral and vertical loading (Smith, 2008). For the purpose of this case study, no changes to the simplified version of the concrete building were made. The precast concrete frames and walls supported by concrete foundation beams which have been redesigned to a simplified version in previous research by Perez (2008). As for the typical floors, the hollow core units remained the same as with the original building. A floor plan of this simplified concrete building is shown in Figure 8(b).



(a) (b).

Figure 8: (a) Artist impression of the simplified concrete virtual building- Source from Perez (2008) (b) Architectural floor plan- Perez (2008)

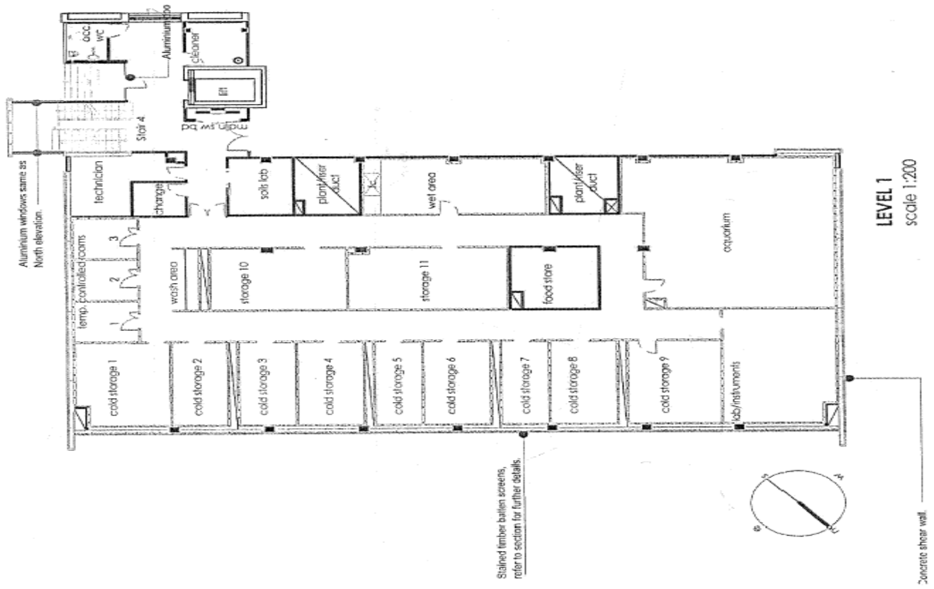
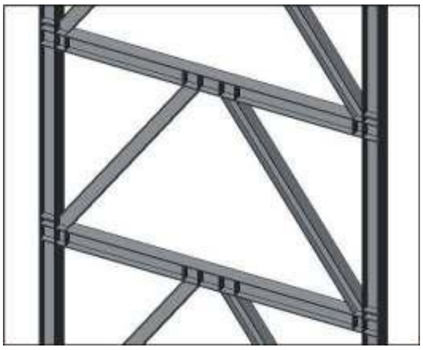


Figure 9: Architectural layout of the original concrete building at Level 1.Reproduced from Dalman Architecture Ltd drawings.

4.4 Steel Building

An architectural impression of the steel building is shown in Figure 10 (a), the structural system of this steel building (see Figure 10b) using Eccentrically Braced frames (EBF's) in both directions. For the purpose of this case study, no changes to this steel building were made. The information of this building was obtained from Smith (2008), which will be used later in Chapter 8 for construction cost analysis. It should be noted that this research will not compare the steel alternative in construction time, as it is expected to remain unchanged to in the construction programme.

(a)



(b)

Figure 10: Steel building (courtesy of Smith (2008))

4.5 The New Optimised Timber Design

The architect’s impression of the new optimised timber building (Pres-Lam building) is shown in Figure 11. The structural layout of the timber design has allowed for a larger open plans, the use of seismic (movement resisting) frames and LVL shear walls of the timber building remained the same as the simplified concrete building. The gross floor area (GFA) of the building is 4300 m^2.

Figure 11: Architectural Impression of Pres-Lam building. Source Perez (2008)

Figure 12 shows the exposed LVL floor joists for the purpose of the case study building, suspended ceiling will be provided as similar to the concrete and steel buildings. Figure 13 shows the cross section of the Pres-Lam building in the east west direction, and Figure 14 shows the cross section at the ventilation chimney of the Pres-Lam building. This new optimised Pres-Lam building was incorporated with the latest techniques of the Pres-Lam system. This was a very high earthquake performance structural building where the building was expected to be damage free after a major earthquake event, and the building would return to the original position (Smith, 2008).

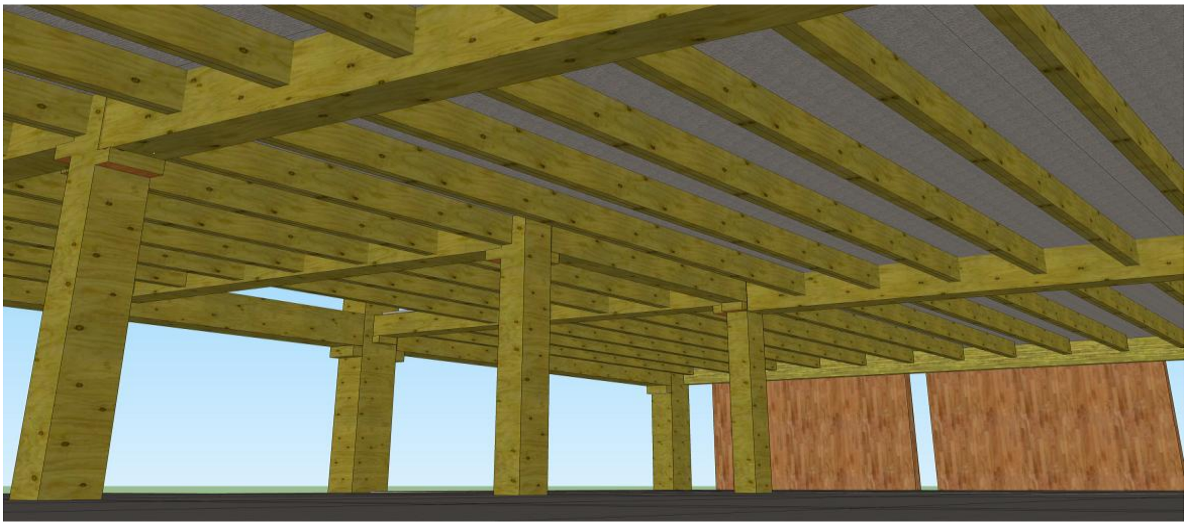


Figure 12: View of the exposed floor system

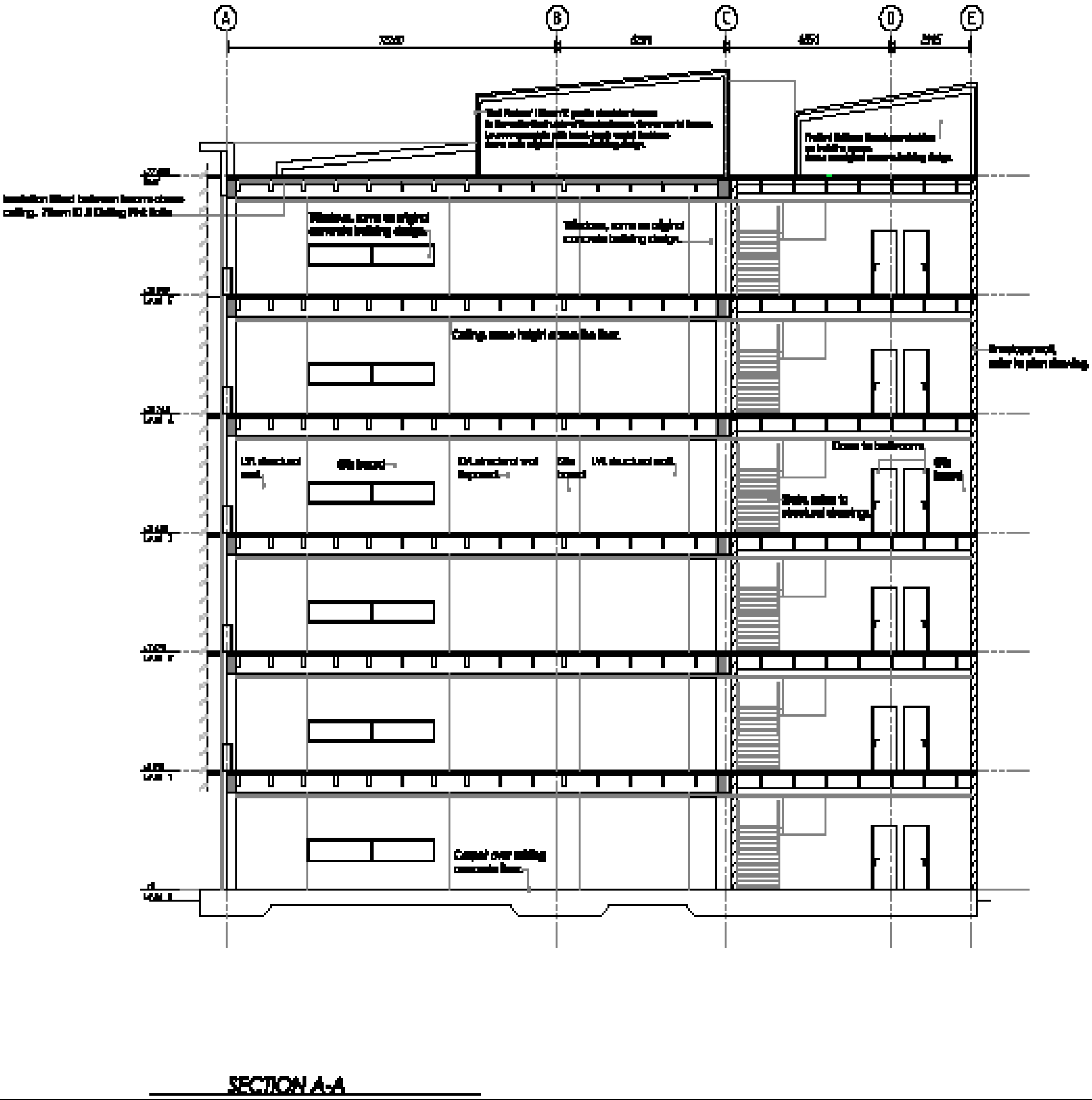


Figure 13: Cross section of the East-west direction of the timber building (source Perez, N).

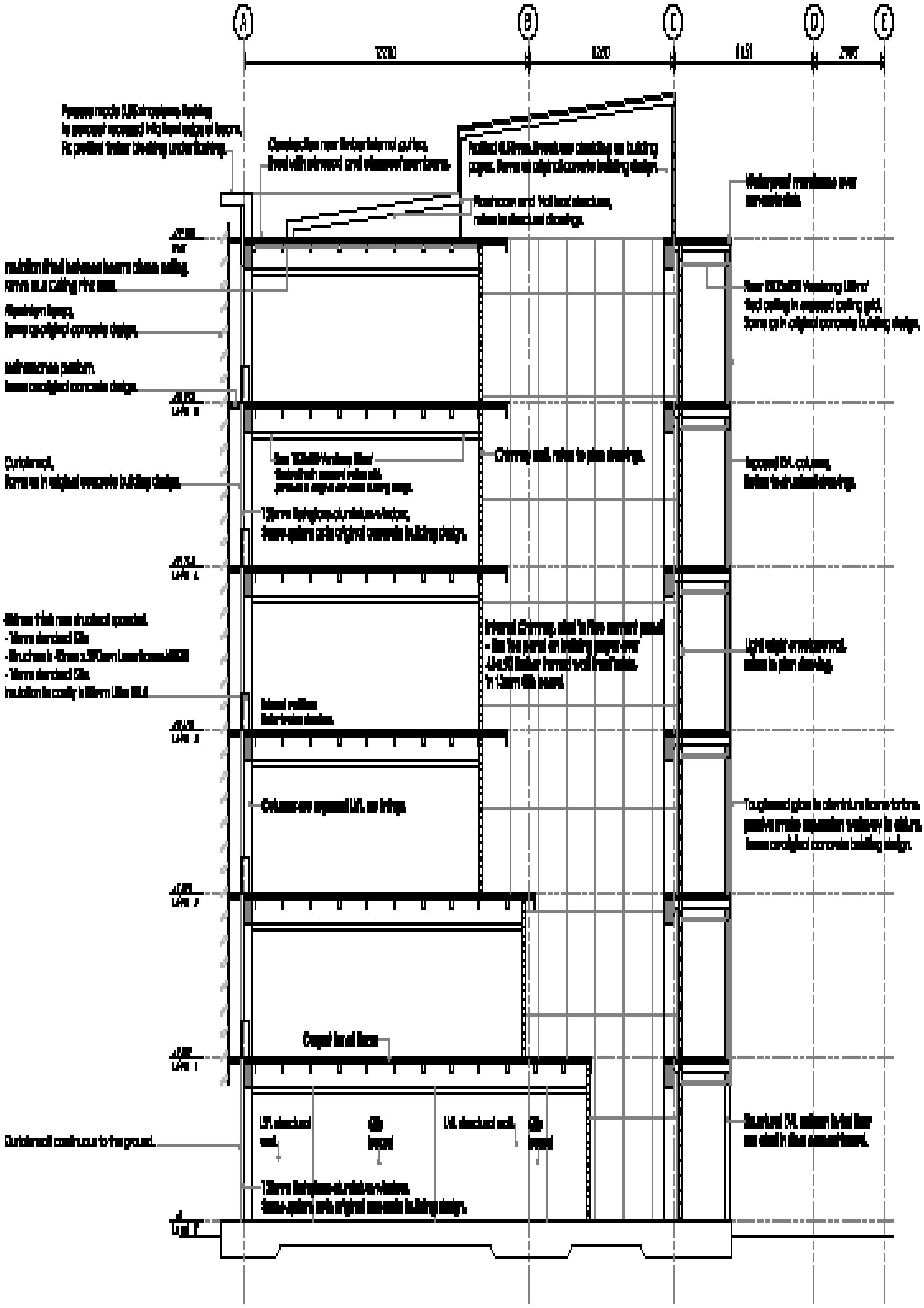


Figure 14: Cross section shows the ventilation chimney of the timber building (source Perez, N).

The external cladding for the walls in the east and west directions comprised of 9mm thick Exo Tec / James Hardie fibre cement panel (externally painted) fixed on 45 $\times$ 25 mm deep timber battens. At the front elevation of the building, curtain wall (toughened glass) and aluminium louvers the same as the original concrete design were used. As for the back or south-east direction of the building, the same type of facade: curtain walls (toughened glass in aluminium frame) were used but doors and other access points to the atrium were excluded. With the intention to optimise the timber building in this research in mind, the author has noted various alternative ways for improvement. This has led to two major changes; increased column spacing thus reduced numbers of columns required so that the structural layout of the timber design will have larger open plans (Figure 16): and the semi-prefabricated TCC floor system has been changed to a fully prefabricated double "T" floor system. The details of the changes will be described below.

4.5.1 Optimisation Design Process

In general practice, buildings are designed and constructed using a mix of materials (hybrid systems) depending on the requirements of the client, the building codes and environmental constraints. The selection factors of materials depend on durability, aesthetics, adaptability, conformity, serviceability and cost. The design decision to optimise must take into consideration the balance between the time and cost implications.

One advantage of Pres-Lam system is that utilising post-tensioning cables in the beams can achieve greater bay width compared with concrete buildings (Smith, 2009). In the Case Study (1), the potential areas to be optimised have been identified to be the structural movement resisting frames and the TCC floor system.

The intention to optimise the structural performance was not aimed at proposing various cheap alternatives so that Pres-Lam system would be cost competitive. This research only considered the ultimate solution by maximising the use of structural timber and used fully off-site prefabricated system. Subsequently these achieved overall higher performances in terms of time efficiency and cost competiveness for the Pres-Lam system. This required a thorough understanding of the past design in order to produce a good constructible building that was more cost effective and time efficient in the optimisation process. The optimisation process provided the ability to increase innovation in both design and construction. Two important questions must frequently be asked during the optimisation process to reduce potential design and construction problems:

- Is the design of the project simple and flexible?
- Are standardised design elements used in the project?

4.5.2 Optimised Design for the Seismic Frame

The optimised design is not part of the scope in this research, the optimised structural design of the Pres-Lam building was performed by UC researcher Michael Newcombe.

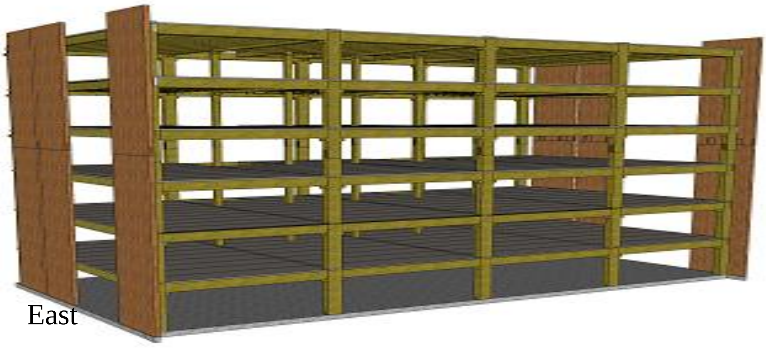
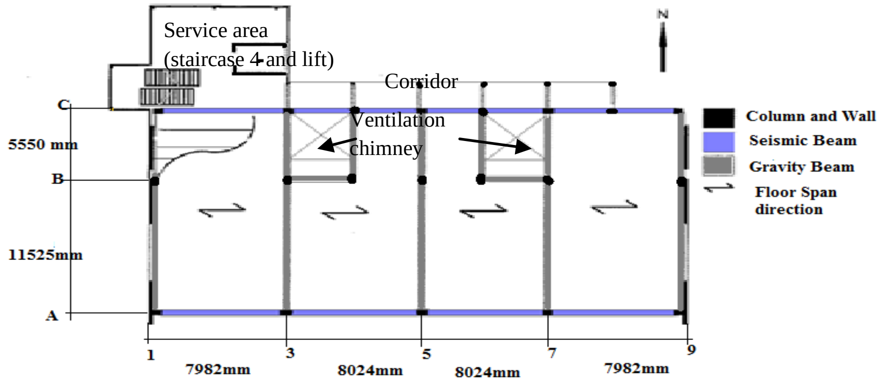


Figure 15: The optimised Pres-Lam timber building

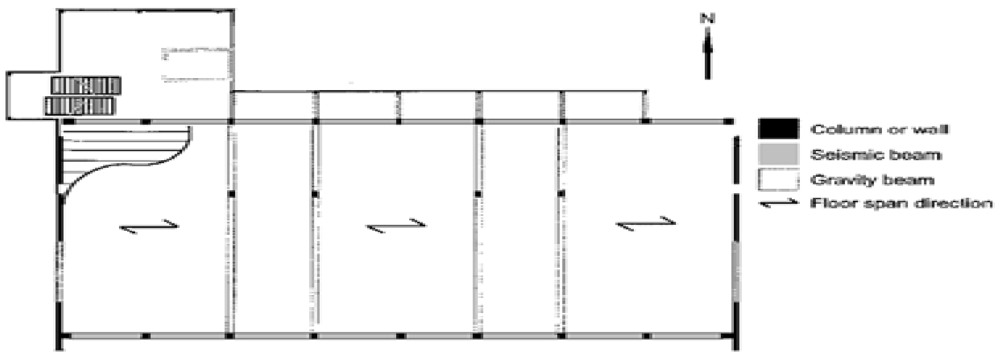
The ultimate load capacity and the serviceability of the optimised design of the LVL structures are determined according to the latest New Zealand timber design codes and Eurocode 5 (2004). The timber building was designed for a life of 50 years and classified as ‘office for general use’ compliance to (AS/NZS1170.1). The response of a multi-storey timber building under earthquake loading is dependent on the lateral force resisting system, the stiffness of the floor and the connection of the floor diaphragm. To calculate the lateral loading of the timber building, the Direct Displacement Based Design (DDBD) method was used. This DDBD design method had been modified, validated (Newcombe, 2008) and successfully applied to this timber building by adapting the DDBD proposed by Priestley et al. (2007) for pre-stressed concrete structures. For more details of how to design a timber building using the DDBD method, refer to Newcombe (2008) and Smith (2008). A copy of the design calculations can be found in the Appendix 2. At the optimising design stage, questions such as how to satisfy the requirements of load bearing capacity and serviceability of the building must be considered. Gridlines, dimensions and the storey height with the proposed beam depths also needed to be taken into consideration.

With the previous timber building design drawings available, the optimised timber structural frame design for the Biological Sciences six storey building was completed. The fundamental difference of this design compared with previous design is that the dead load of 2.5kpa. Smith’s (2008) used more conservative estimates in assuming the lateral load was taken only by the frames and assigned too much mass to the floors. He assumed the dead load to be

3kPa, live load of 3kPa plus a superimposed dead load of 0.5kPa was used. The Risk Level was assumed to be 1.2 for "Student Building" in this design**.** The structural design calculations can be found in Appendix 1. The differences between the optimised structural timber building plan and the Smith (2008) timber building structural plan are shown in Figure 16(a) and in Figure 16(b) respectively. The service area including the staircase, corridor and the lift shaft added additional mass contributing to the total gravity loading in each floor as highlighted by previous researchers.



16 (a)



16 (b)

Figure 16: (a) Structural plan of the optimised Pres-Lam building at level 2 (b) Structural plan for Smith (2008) timber building.

Therefore these items will not be considered in the calculations. However as for the cost comparison, these service areas will be included in both the timber and concrete design. The cross sectional dimensions of the seismic beam and column are shown in Figure (17). 90mm LVL panels are used instead of 63mm LVL panels used by Smith (2008), hence the fewer layers of LVL laminated will have cost reductions in fabrication as mentioned in Chapter 1.

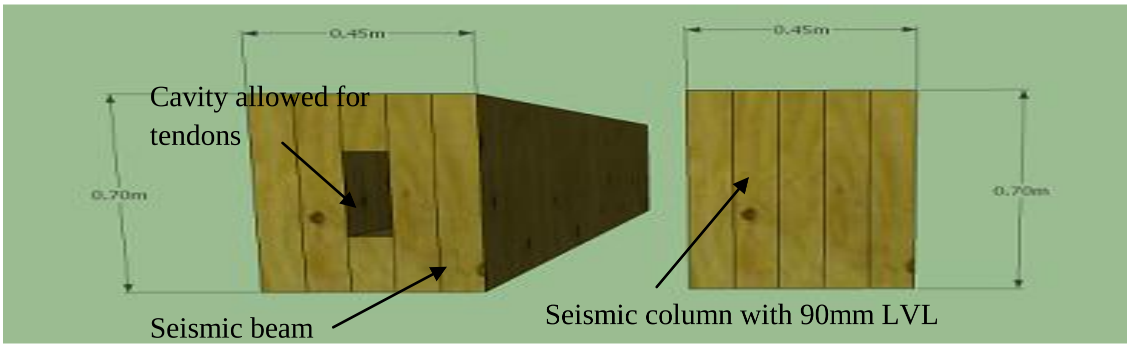


Figure 17: Cross section for Seismic Beam and Column.

At the east and west ends of the building, three shear walls of 4000mm x 252mm are used. The layout, quantities and dimension of the shear walls remained unchanged. U shaped flexural Plates (UFP) for energy dissipation developed by UC for the wall will not be used in this Case Study. The cross section of the shear wall is shown in Figure 18. MacAlloy 1030 bars will be used instead of Post-tensioned tendons to resist the lateral movement for the wall system is due to its efficiency.

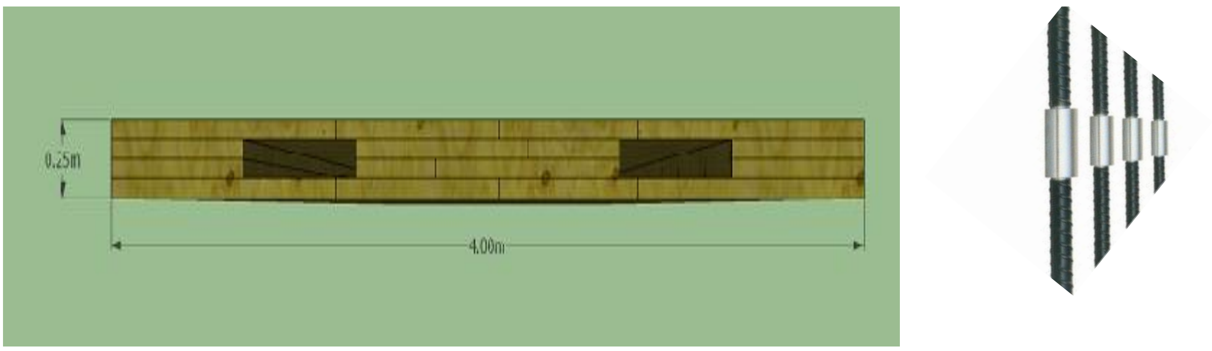


Figure 18: (a) Cross section and LVL shear wall (b) MacAlloy bars with couplers

The optimised timber building member sizes for comprises of beams, columns and wall cross sections are compared with the concrete building in Table 1. The cross sectional areas for both materials are found to be comparable, however the weights (mass) of the timber members are 25% that of the concrete members. The timber member sizes are much lighter, therefore there will be mass saving in timber building as compared with concrete building.

Table 1: Comparison between Timber members and Concrete members

	Timber (Optimised)			Concrete		
Member	Size (mm)	Area (m^2)	Weight (tonnes)/m	Size (mm)	Area (m^2)	Weight (tonnes)/m
Beam	700 × 450	0.3	0.2	800 × 400	0.3	0.8
Column	700 × 450	0.3	0.2	800 × 400	0.3	0.8

Wall	4000×252	1.0	0.6	4300×200 (with 110 insulation infill)	0.9	2.0

The total mass reduction of LVL savings from the optimised process did not offset the overall total dead load (G) of the timber building. The column weights were sufficiently small when compared with the concrete floor, thus resulting in a very minimum reduction. Therefore the foundation design will remain unchanged. Seismic frames and shear walls are supported by foundation beams (see Table 2), and two shallow pad foundations are used to support the gravity columns. However, Smith (2008) has highlighted that there will be significant cost saving in the foundations for the timber and concrete building if the buildings are to be built in a non-seismic (gravity dominated) region or located in a soft soil area.

Table 2: Foundation sizes for timber building.

Location	Types	size of foundation
Ground floor (level 1)	Reinforced Concrete slab	200 mm thick
Grid lines A & C	Foundation beams	1200×600 mm
Grid lines 1 & 9	Foundation beams	1400×600 mm
Grid line B	Raft foundation (2 no)	300mm thick by 5.3 m $\times$ 5.3 m
Grid line C'	Pad foundation (6 no)	$300 \times 300 \times 200$ mm thick

4.5.3 Optimised Design for the Floor System

Several alternative timber floor systems were investigated and compared prior to choosing the fully prefabricated double "T" LVL concrete composite floor system also referred to as double "T" for this research. The advantages and disadvantages of these timber floor systems are described in Chapter 5. Based on the intended ideas for improvement in the floor system in mind, David Yeoh was chosen to perform the floor design because he has extensive experience and is also one of the pioneers in the development of the semi-prefabricated floor system at the University of Canterbury.

The design is in compliance with New Zealand design code NZS 3603 (1993) as well as reference to Eurocode 5 (2004) limit states design satisfying the following criteria were used:

1. Short-term Ultimate Limit State (ULS) and Service Limit State (SLS)
2. Long-term Ultimate Limit State (ULS) and Service Limit State (SLS).
3. Vibration check for 1kN point load.

According to Yeoh, the floor joists have been designed for ULS and SLS load combinations. A 2.7 kN point imposed load was applied at the mid-span of the beam, and the deflection was checked. Long-term deflection has also been checked and found not to be critical in this case. In this case the shear in the connection between the concrete topping and the floor joists governed the design instead of long-term deflection. This is because the strength and stiffness of the plate connection is not as high as the notched connection. The precast concrete topping was designed according to New Zealand concrete code NZS 3101 (1996). Grade 30 MPa low shrinkage concrete (CLSC) will be used for the double “T” floor unit. The design calculation for the TCC double “T” floor system can be found in Appendix 2. The details of the double “T” floor system will be described in Section 5.3.

4.6 Summary

The original design of the Biological Sciences building featured complex layouts and some minor changes to the original concrete building especially at basement level were necessary. The entire basement level (concrete box) and the atrium link way to the adjacent building have been removed in the Case Study (1) virtual buildings (concrete, steel and optimised timber). For the purpose of this case study (1), no changes to the simplified version of the concrete and the steel buildings were made. Present research has optimised the performance of the Pres-Lam system and a greater open space with larger column spacing has been achieved. The proposed fully prefabricated double “T” TCC floor unit was used. Based on these optimised designs, the construction programmes and the construction costs estimation are further described in Chapter 7 and Chapter 8, respectively.

Chapter 5: LVL Timber Floor Systems

5.1 Introduction

In the early 1950, interest in TCC floor construction actually came from construction of bridges and upgrading of old timber floors. Recently, interest in the TCC floor system has increased and this has lead to many countries around the world such as Australia (University of Sydney), New Zealand (Buchanan et al., 2007, Yeoh et al., 2009, 2010), United States of America, Italy (Fragiacomo et al., 2007 and Lukaszewska et al., 2007), Germany (Bathon et al., 2006), Austria, Sweden and other European countries investigating and trying to develop high performance TCC floor systems.

This chapter will discuss the advantages and disadvantages of three different types of timber floor systems. The three floor systems are: the semi-prefabricated TCC floor system developed by the University of Canterbury, the Potius Stressed skin LVL floor system, and the proposed fully prefabricated TCC floor system.

5.1 Timber Concrete Composite Floor Systems

The TCC floor system is also widely used in Europe for new and existing construction (Ceccotti, 2002). Timber concrete composite (TCC) flooring systems have been around since the 19th century, and are commonly used in Europe for retrofitting old timber floors in buildings and bridges with a concrete slab topping. Concrete performs well in compression and timber beams are strong in tension and bending. The two materials, concrete and timber, are joined together using interlayer shear connectors (figure 19). Interlayer shear connectors in a TCC are normally placed along the floor joists in the form of fasteners (nails, coach screws, toothed metal plates, steel bars and other) that can be use to connect the concrete topping to the timber beam. This combination increases the strength and stiffness performance of the materials, and reduces deflection through effective composite action. The University of Canterbury, with the backing of STIC Ltd, has developed a new type of floor system called the “M” section semi-prefabricated LVL concrete composite floor (Buchanan 2007, Yeoh et al, 2008, 2009, and 2010). This floor system (Figure 19) is 2.4 metre wide and is semi-prefabricated off site with double LVL floor joists of 63×400mm, spaced at 1200mm centres. 17 mm plywood sheathing acts as a permanent formwork for the concrete topping. The cast in-situ 65mm thick concrete topping is reinforced with a layer of steel wire mesh (see Figure 19). The shear connections have coach screws that require notches to be cut in the floor joists and in the plywood to achieve composite action. This allowed TCC floor system to accommodate larger loadings and longer spans when compared to traditional timber construction.

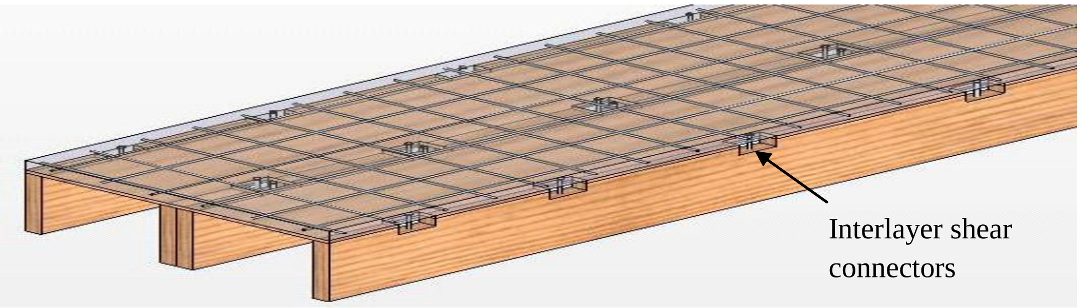


Figure 19: The “M”-section semi-prefabricated LVL concrete composite floor system, source from Smith (2008).

The current “M” section semi-prefabricated TCC floor system developed at the University of Canterbury has many advantages:

- With side couch screws installed at the side perimeter beams, floor diaphragm action can be achieved, hence increasing the stiffness of the Pres-lam structural system.
- Medium to longer span floor panels ranging from 6 to 12 metres are possible (Yeoh et al., 2009).
- The floor panel is very light weight, therefore easy to handle.
- The addition of the concrete topping improves the fire resistance rating (O’Neill, 2009), thermal mass, acoustic and vibration performance (Nor Abd Ghafar et al, 2008) for the floor system when compared to traditional timber construction.

However, this type of floor system is still not the optimum solution to the floor system in timber buildings. An optimum floor system meeting all the requirements of weight, acoustics, vibration, fire protection, energy efficiency, durability, aesthetics, sustainability and cost effectiveness is still under investigation in Australia and countries around the world. Current fabrication processes for semi prefabricated TCC floor units is time consuming and labour intensive, especially in the manual cutting of the notch connections, making it less cost effective. During construction, temporary propping will be required for this floor system. Long-term deflections of floor spans exceeding 10m need to be designed carefully in order to satisfy the deflection limitations. As such, a deeper floor system joists or smaller tributary width floor panel (Yeoh et al., 2010) may be required. It may be more cost effective to use alternatives floor systems with less labour costs. Therefore in this research other alternatives floor system such as the “Potius floor system (stressed skin) and the fully prefabricated double “T” floor system have also been investigated.

5.2 Potius floor system

The Potius floor system as shown in Figure 20 is a relatively new product developed by Potius Building System Limited and manufactured in Nelson, New Zealand. This type of floor panel is a stressed skin LVL composite floor system. This floor panel normally comes in 1200mm wide sections; however it can be fabricated in variety of configurations to create longer spans (maximum up 12 metres span) depending on the client requirements. Potius is an “M” section with regular LVL webs and 36mm thick cross banded LVL top flanges. There are glued together to form a composite panel. Potius has the advantages of being lightweight, high performance and easy to transport and install. Prefabrication of this type of floor panel will be less labour intensive as compared to other flooring systems. Potius floor panels are hung on the flange, which can eliminate the use of floor joist hangers.

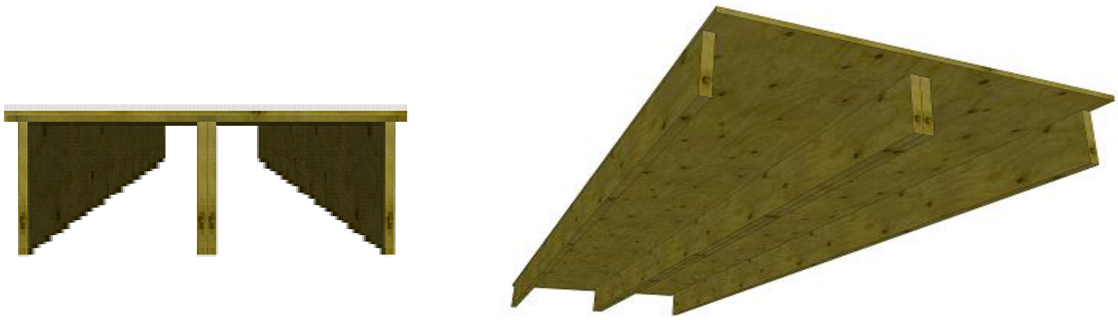


Figure 20: Potius floor system

This Potius system was used in the Nelson Marlborough Institute of Technology (NMIT) project, the world first Pres-Lam timber structure currently under construction in Nelson (2010). However, the Potius floor system by itself does not have the mass to meet other important serviceability criteria of a building such as acoustic separation, vibration performance, fire protection, and thermal mass for energy efficiency. Therefore additional costs in the ceiling, under floor gypsum layer and concrete topping to increase the mass to improve the serviceability of the floor system make it less cost effective as compared to other alternative floor systems. A cost comparison of the three timber floors system has been evaluated (see Appendix 3) and has found that the Potius panel is not the preferable optimum alternative floor system for this case study Pres-Lam building. Nevertheless the Semi-prefabricated TCC floor system and the Potius floor system as described above are good floor systems, their application in a project varies accordingly depending on the suitability and preference.

5.3 The Proposed-Fully prefabricated Double "T" Floor System for Case study (1) Pres-Lam Building

A fully prefabricated double "T" floor system referred to as (double "T") is particularly well suited to multi-storey building construction, because it can avoid site concrete pouring which is labour intensive and cost and time consuming. Similar TCC panels have also been developed and used in Germany (Bathon, 2006) by HBV®-Systeme for existing retrofitting and new construction (see Figure 21 and Figure 22). Double "T" is a long span floor system, fast to erect and under floor propping is not required, therefore it is quicker to erect and cost effective. For the semi-prefabricated TCC floor panel used in Smith (2008), plywood contributed 13 % of the total cost of the floor system. The removal of the permanent thick plywood sheathing form this floor system will immediately have huge cost savings.

Figure 21: Fully prefabricated TCC floor system developed in Germany. (Photos source: HBV®-Systeme website).

This double "T" system is intended to optimise LVL and concrete usage. In many cases, using double "T" TCC constructions results in a lower first cost than alternative floor systems because LVL timber floor joists are light and have high strength; ready mixed concrete and concrete prefabricator are usually locally available, and special labour skills are not required. The load-bearing capacity of the double "T" composite system depends on the level of composite action developed by the shear connectors. A high performance double "T" floor system should have shear connectors that satisfy the following parameters: cost effective, ease of production and ease of assembly, and stiff and strong as suggested by Yeoh et al. (2008). Toothed metal plates (Mitek™© plate) are the preferred shear connections for these double "T" sections because this can eliminate the time consuming process of cutting notches in the floor joists. Staggered toothed metal plate (2 $\times$333mm) connections (12 per double beam) will be used along the length of each beam when placed adjacent to each other. A continuous length of shear connectors will be placed in the double beams. It can be manually fixed, but by using an industrial size hydraulic pressing machine, the installation of metal plates will be much more efficient and cost effective (Yeoh et al, 2009).

To avoid problems with long term deflections, pre-cambering of the LVL floor joist and the concrete can be done during the fabrication process. During the pre-cambering, the floor joists have two mechanical jacks at both ends and one in the middle of the beam which pull down and push up to create a convex curve. The recommended measurement for the convex profile in this case is 30mm (length of span is 8650 divided by 300). The casting mould for the concrete will have to be a convex profile as well.

The preliminary finding at the University of Canterbury (Abd Ghafar et.al, 2008) on the vibration of floors concluded that 8 metres of 1200mm wide tested floor has measured frequencies of 9 Hz, and 10 metres of 600mm wide tested floor has measured frequencies of 6 Hz. The floor samples tested were made up of 400mm LVL floor, double joists of 63mm thick with 17mm thick plywood sheathing and a 65mm concrete topping. According to (AS/NZS 1170.0:2002) and Eurocode 5 (EN 1995-1-1: 2004) the fundamental natural frequency limit of 8 Hz for the lower frequency residential timber floors must be achieved. The proposed double "T" floor span is 8.65 metres and using high strength low shrinkage concrete with a thickness of 75 mm has been proposed for this double "T" floor system (see Figure 22 and Figure 23). Figure 25 shows the 75mm thick precast concrete is reinforced with a layer of steel wire mesh (D10-200mm centres both ways). At the cantilever flanges of the precast slab, a layer of steel reinforcement (D12-300mm centres) is provided to resist tension force.

So that the separation between the joists will not occur as mentioned earlier in Section 3.5 by O'Neill (2009), the latest findings by researcher Tsai (2010) investigating the fire performance of floor system through personal communication advised that treaded M12 coach screws of 100mm long at a spacing of 150mm centres (staggered) will improve the overall fire performance of the double floor joists significantly.

Figure 22: Fully prefabricated double "T" floor panel.

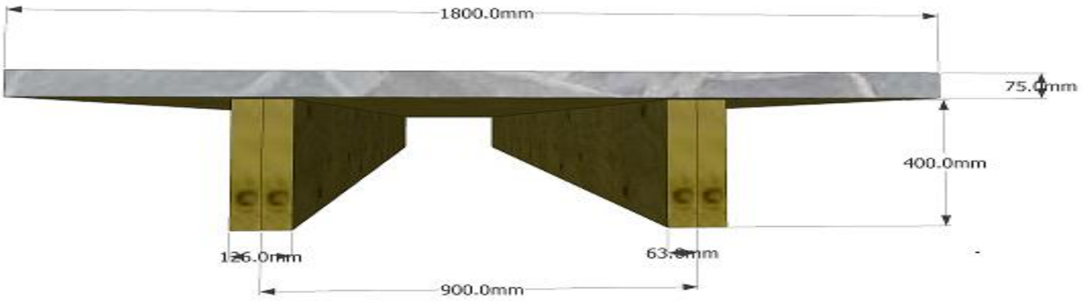


Figure 23: The dimension a for double "T" floor unit used in the Case Study (1)

The measurements of the LVL floor joists for this building are 8.65 m $\times$ (2 $\times$ 63 mm) $\times$ 400 mm. The fabrication process of the double "T" section is relatively simple:

- **Step 1**-At the fabrication factory the LVL floor joists were cut and fabricated according to the required size.
- **Step 2**-The metal plates (Mitek™) that act as the shear connectors are pressed into the floor the joists (Figure 24) which are joined together with coach screws to become double joists and later sent to the casting yard.

Figure 24: Pressing the metal plates to the LVL floor joist, source from O'Neill (2009)

- **Step 3**- At the precast factory, there are two ways of fabricating the double "T" floor units. The concrete slab can be poured into a steel mould in the upright position (Figure 25(a)) or the upside down position (Figure 25(b)) depending the pre-caster choice whichever is easier and cost effective. The floor joists will be placed in position with the metal plates protruding in the slab ready to be poured (Figure 25(a)). Pipe sleeves with concave counter sinks will be provided for M16 fasteners to attached concrete flanges to future beams. Steel angle will be at both top ends in the finish level of the concrete flanges before the concrete is poured. Steel reinforcement and wire mesh are placed and the 75mm thickness concrete slab poured in a horizontal position at the factory.

- **Step 4**-Once the concrete slab is hardened, the slab will be removed from the steel mould. The completed double "T" is then stored at the yard and ready to deliver to the construction site as required.

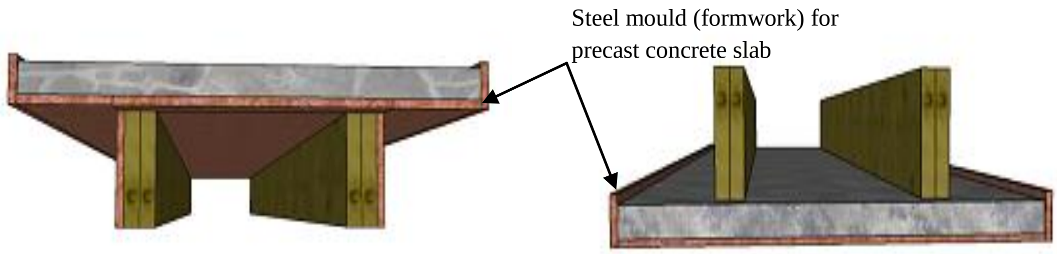


Figure 25: (a) Double "T" floor unit in upright position during prefabrication process (b) Alternatives pre-casting method – (upside down position)

5.3.1 How to Achieve Floor Diaphragm Action in Proposed Double "T"

The double "T" floor units were flange (75mm thick concrete slab) hung on the beams (see Figure 26 and Figure 27). The weight and span of the floor unit (average 4.1 tonnes per panel) were relatively high, and gravity and live load of the floor system must be distributed to the seismic frames. How it achieve floor diaphragm action in the TCC double "T" is outlined in the following steps:

- When the floor unit is placed, each floor unit will be connected using M16 coach screws at 500mm centres on top at the perimeter of beams (seismic, primary and edge beams). At the edge of the pre-cast slab, screws holes of 18mm diameters with a concave cup of 50mm diameter near the top are allowed at the factory. After the coach screws are attached, the concave holes in the double "T" concrete slab will be grouted.
- The adjacent floor panels are joined together in the longitudinal direction with a piece of steel rod placed in centre and are then welded with 6mm fillet welds on both sides (see Figure 28).

Once the holes are grouted, the floor loadings are evenly distributed to the beams, increasesing the strength and stiffness of the movement resistance frames and walls of the building.

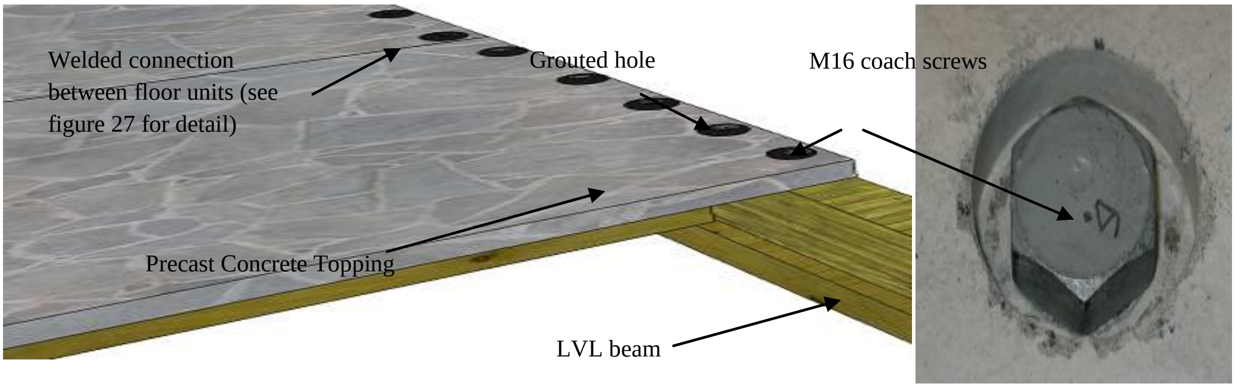


Figure 26: (a) Floor diaphragm connections to beam (b) Top view M16 coach screws

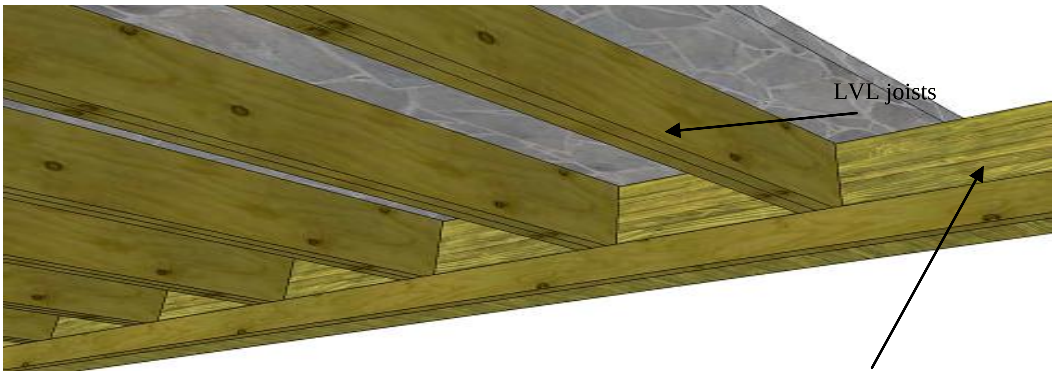


Figure 27: Floor to beam connection

By using precast concrete in this floor system, a common problem may arise due to the variance in the thickness of the finished precast slab. This problem had been highlighted by the Mr Graeme Jones professional project manager from (Arrow International Ltd.) and the project director Mr Andrew MacGregor from C. Lund & Sons Ltd. A layer of non-structural self levelling cement sand screed (see Figure 28) or grout will be provided to achieve the required level, as well as covering the welded steel joints.

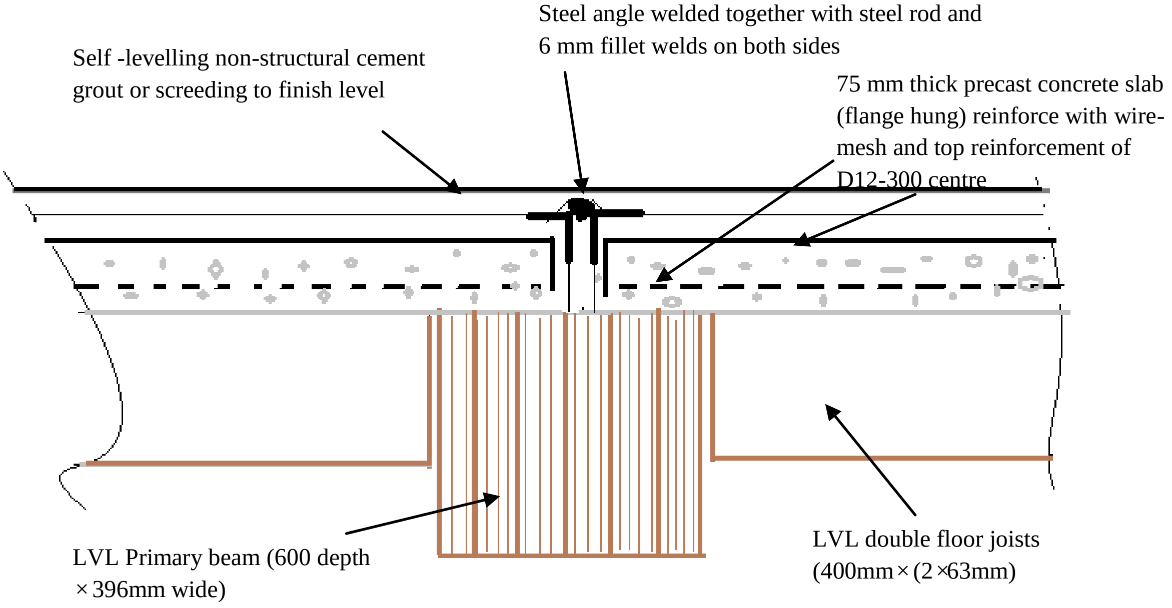


Figure 28: Connection detail between adjacent floor units

5.4 Summary

Three timber floor systems were compared and the proposed double "T" was chosen because it is a fully prefabricated floor system. Other advantages of the double "T" floor system are because it is light and high strength, temporary props are not required. Therefore it is a rapid construction floor system and the unit rate per square metre of this floor system is comparable to other alternative timber floor systems. It should be noted that, no provision for acoustic separation and other serviceability design requirements have been incorporated into this floor system in this research.

Chapter 6: Construction of the Virtual Pres-Lam Building

6.1 Introduction

A different approach consisting of balloon and frame construction method was used in this optimised Pres-Lam building in Case study (1). This type of construction method can increase productivity and efficiency as compared to the more commonly used traditional single storey platform construction method, as described in the following sections.

The construction method used in this research was different from Smith's 2008 research, which divided the floor plan into three sections. Installation of the timber building in previous research began with the shear walls at Grid Line 1, and was followed by the seismic columns, beams and semi-prefabricated TCC floor units at Section 1 (from east direction working down towards west direction). Smith (2008) used the balloon construction method to analyse the construction time of the timber building. Platform construction method was used in the concrete building due to the size and heavy weight of concrete precast components.

6.2 Balloon Construction Method for the Virtual Pres-Lam Building

The term "balloon construction" was originated from timber framing construction where the continuous vertical timber framing of a several storeys high from the base (sill plate) to the top (eave line) of the building. The advantage of the Pres-Lam system is that balloon construction can be used due to the use of lightweight prefabricated LVL components. A cubic metre of concrete weighs approximately 2.4 tonnes, while LVL components can weigh as little as 0.55 tonnes per cubic metre (approximately 4 times lighter than concrete). A single storey concrete wall panel weighs approximately 8 tonnes and a three storey concrete tilt-up wall panel weighs 24 tonnes. If balloon construction were used in this concrete building, a much larger crane would be required, making it less cost effective.

The optimised Pres-Lam building in Case Study (1) uses the construction method referred to as balloon frame construction and solid LVL shear wall panels. This building is estimated at 22.9 metres high for the columns and 23.9 metres high wall panels to be divided into two full lengths of 11.4 metres and 11.9 metres respectively. The columns and walls are spliced at the mid-span of fourth level. In prefabrication manufacturing the bigger panels have virtually the same labour content as smaller panels, therefore it would be more cost effective to have the prefabrication components as big as possible. This is one of the main advantages of using LVL; the members can be fabricated to any required length as long as the available transport can be supplied. In general, a maximum length of 15 metres would be the most preferable due to commercial transportation limitations.

The frames at Grid Line (1) and (9) consisting of columns and edge beams would be levelled, aligned and assembled horizontally on the ground on site once the LVL members had arrived and later the entire frame will be lifted up into position. The corner of the frame (seismic column) would have three notches cut into it to allow for the edge beams (Figure 29). Once the edge beams are placed, it would be screwed together using Type 17 screws. Once the frame was assembled, the straightness and the diagonal measurements must be checked prior to erection. The assembly of this frame was estimated to utilise four workers should only take one hour. These end frames were the largest Pres-Lam components for site erection. The size of the end frame was 12.1 metres long (including the splicing finger of 650mm) by 18.2 metres wide, weighing 7.23 tonnes (Table 3).

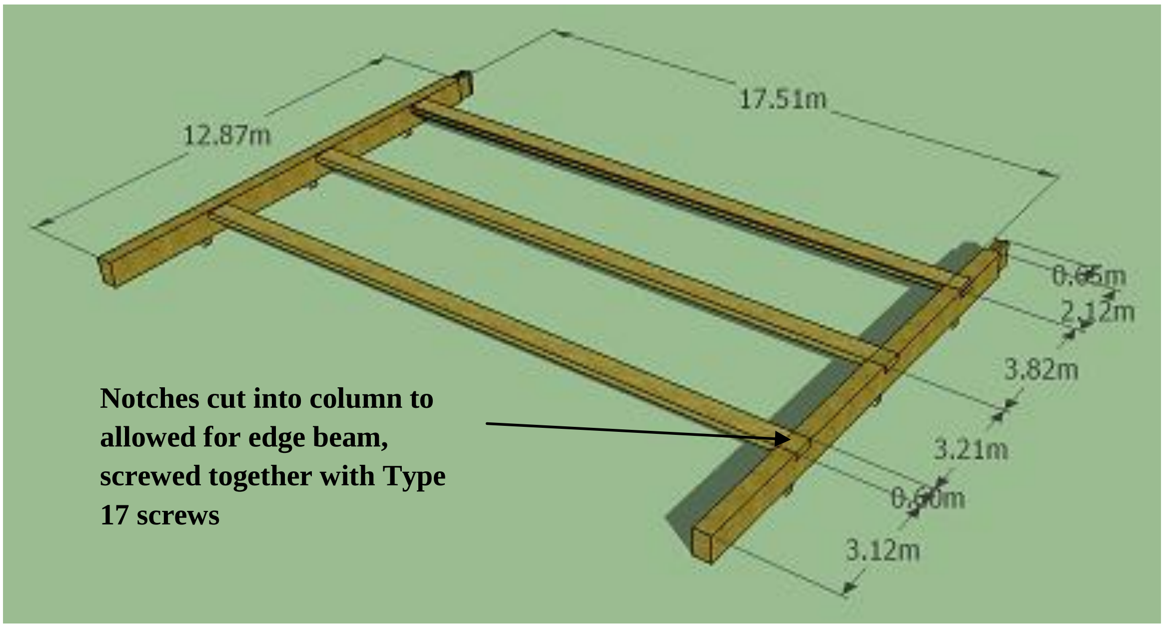


Figure 29: End Frame at gridline (1) and (9) assembled on site prior to erection.

Alternatively the optimised timber building could be constructed by assembling the frames (along Grid Lines A and C) in a segmental fashion horizontally on the ground. The frames would be then post-tensioned and tilted upright into position. However, this construction method would require a heavy lifting capacity crane (approximately a 12 tonnes tower crane) to do the lifting. This was not considered in this research.

Table 3: Weight of timber building structural members (Note: Frame, column and walls are 3 storeys high)

Item	Length (m)	Width(m)	Depth(m)	Qty	Density (tonne/m3)	Weight (Tonne)
Seismic column	11.45	0.7	0.5	2	0.55	4.41
Edge beam	18.4	0.189	0.6	3	0.55	3.44
					Total weight of Frame	**7.23 Tons**
Weight of individual member						
Gravity Column	11.45	0.45	0.27	1	0.55	0.76
Seismic column	11.45	0.7	0.5	1	0.55	2.20
Edge beam	18.4	0.189	0.6	1	0.55	1.15
Shear wall panel	11.93	4.0	0.252	1	0.55	**6.61 Tons**
Seismic beam	7.982	0.45	0.7	1	0.55	1.38
Primary beam	11.615	0.378	0.6	1	0.55	1.49
Gravity beam	5.55	0.378	0.45	1	0.55	0.48
Tie beam	3.462	0.27	0.45	1	0.55	0.23
Fully prefabricated double "T" floor unit						
Concrete	8.543	1.8	0.1	1	2.4	3.69
Floor joists	8.165	0.063	0.4	4	0.55	0.41
					Total weight of floor	**4.10 Tons**

6.2.1 Different Type of Lifting Capacity Tower Crane Used for Construction

It is essential to identify the type of crane that would be used for the construction of the building because this would affect the overall constructability of a project. The existing tower crane used for the actual concrete building was a Liebherr 280 EC-H 12 FR-tronic with a maximum lifting capacity of 12 tonnes, however when the crane boom was extended to 70 metres, the lifting capacity was only 2.5 tonnes. For this case study, the Grid Line (C) was the longest distance which was located with radius of 31 metres from the proposed tower crane site, providing an allowable lifting capacity of 11.8 tonnes. (Refer crane capacity drawings provided by C.LUND & SON LTD in Appendix 3). To allow for a realistic comparison, a much small tower crane of 8 tonnes was used for the optimised timber building due to the weight of the timber building. Using a much small tower crane would immediately result in a huge cost savings. This cost comparison will be described in Chapter 8.

6.2.2 Site Preparation and In-situ Ground Works

Site clearing and project construction activities increase surface storm water runoff and ground water runoff from the construction site, which needs to be managed properly. Therefore before any works could proceed, the following tasks must be carried out:-

- Identify and construct the sediment basin and sediment traps
- Locate key run-off control measures in conjunction with sediment traps to divert water
- Install run-off conveyance (dewatering) system

Once the sediment and erosion control measures were in place the site clearing could begun. The construction work of the building was planned to commence from the east to the west direction. There are a total of four perimeter foundation beams and two pad foundations for the gravity interior columns at Grid Line C. The construction sequence of the foundation beams began with the excavation of the trenches: hard fill was laid and compacted; formwork placed; reinforcement placed and fixed; insert hold down bolts (anchorage) for the steel shoes for columns and walls, and the foundation beam was poured. The formwork was stripped during the following days, and the next step was to backfill and compact to the lower level (soffit) of the ground slab. Reinforcement and wire mesh are then placed. The concrete ground slab would be poured in a single operation and power floated to the required finish. The preparation works for erection of the prefabrication Pres-Lam could begin following the completion of these tasks.

6.2.3 Erection Sequence of the Pres-Lam Structure

Normal construction practice must allow sufficient time for the concrete to be cured (28 days) and to gain strength. In order to expedite the construction process, a higher strength concrete could be used. The erection sequence for Pres-Lam was slightly different from concrete buildings where precast components could be placed after the completion of the foundation beams. The Pres-Lam timber building, similar to other traditional timber framing buildings, requires the concrete slab to be completed before the erection work could start. It is a good practice to keep wood products such as LVL members away from the ground and especially moisture. The concrete slab also provides the system with a reasonably level solid base to work from. Prior to the erection of the Pres-Lam structural members, the steel shoe connectors for the columns and shear walls must be levelled, aligned and fixed in position.

The erection sequence for the first three storeys of the timber building is outlined in the following steps:

- **Step 1** Three Ø32 mm MacAlloy 1030 bars were placed in the each of the wall cavity from the top of the wall, and were fastened to a 25 mm thick bearing plate with nuts. Workers lift up the LVL shear walls panels which were on average 11.5metres high, 4 metres wide and 252 mm thick, weighing 6.6 tonnes (Figure 30(a)). At 1 m above ground level, the reinforcement bars at the base of the wall were screwed into the couplers provided in the column base at the factory before lowering into position. These protruding bars were then inserted to the Reidbar™ grout sleeve provided in the concrete base. Refer to the wall base connection details in Section 6.3.2. The walls are then moved into position and placed at Grid Line (1). **Note**: only two of the walls can be placed at one time. This is because the wall panels at the corner near Grid Line (1) and (9) could only be placed once the post-tensioning works were completed at the column face.
- **Step 2** The end frame at Grid Line (1) is assembled on site as shown in Figure 29 (Section 6.2) would be lifted up, similar to the wall base connection, and repeat the steps (refer to column base connection details in Section 6.3.1). The frame is then slowly moved into position and placed at Grid Line (1). The frame (Figure 30(b)) is then accurately plumbed and propped, this frame serves as the guide for the remaining components. LVL components have the advantages of being able to be securely fastened with temporary bracing without the less cost effective predrilled insert plates that normally are used in concrete components.
- **Step 3** The next step was to place the columns and beams within the first bay (Figure 30(c)). This provides extra bracing to the erected frame. The beams were rested on top of the timber corbel and attached with screws. This provides an immediate support for the beams, while the laying of the post-tensioning tendon could start once the first bay seismic beams were placed. The post-tensioning workers would work concurrently with the erection teams on-site.

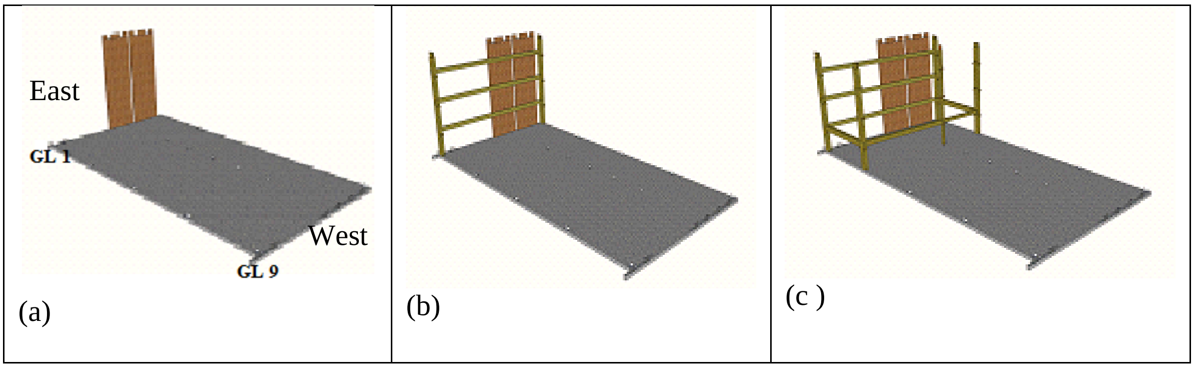


Figure 30: (a) Erection sequence of the first three storeys –walls (b) Frames at gridline (1). (c) Columns and beams placed at 1st bay.

- **Step 4** The installation of columns and beams for the building progress towards the west direction up to the end frame and walls at Grid Line (9). At this stage the post-tensioning tendons were placed. In the following days the tendons could be stressed at the four ends of the installed frame at Level two. After the tendons were stressed, the frames and walls would be very stable and securely braced. At this stage some of the temporary bracing could be removed. The installation of the double "T" floor panels starts at the 1st bay level two (Figure 31(a)).
- **Step 5** As the double "T" floor units were placed in the 1st bay (Figure 31(b)), the corbels at the beam locations provide an immediate guide, support and level to the floor units. The floor units are flange hung on the beam. M16 coach screws would be attached to the top of the seismic and edge beams. This would further increase the rigidity and stabilise the structure during construction, and floor diaphragm action would be achieved. The concave holes in the double "T" concrete slabs would be grouted once the Level Two double "T" floor units were placed. The double "T" floor units at the third and fourth levels would not be placed until the seismic beams were post-tensioned. The adjacent floor panels are joined together in the longitudinal direction with a piece of steel rod placed in centre and are then welded with 6mm fillet welds on both sides. The double "T" floor units weigh 4.1 tonnes and require a very stable supporting structure during construction. As the installation of double "T" floor panel progresses towards the west direction, subsequently the third level was started before the completion of second level. Each complete floor would serve as a working platform, reducing the need for temporary works. At this point the architectural fit out and other mechanical, electrical and plumbing work could begin at Level One.
- **Step 6** (Figure 31(c)) The next step was to install all third level beams, followed only by the fourth level seismic beams to be placed. If all fourth level beams were placed

prior to the installation of double "T" floor panels, it would create obstructions during installation. Once the seismic beams and tendons were installed, the third and fourth levels seismic beams were stressed. The two corner end walls could be placed once all the beams were stressed at the column face. It is a good practice to have the post-tensioned anchorage concealed in the column rather than at the shear wall panel at Grid Line (A). This is a very critical point that previous research did not take into consideration.

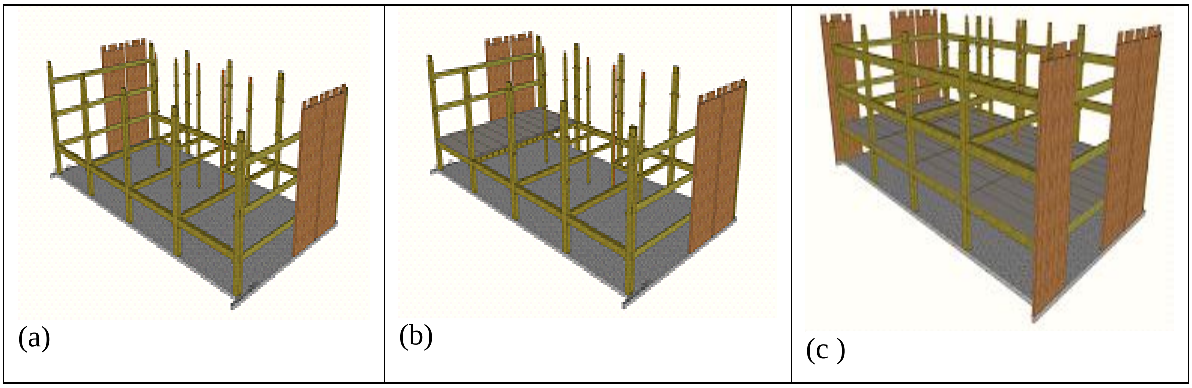


Figure 31: (a) Construction of first three storey walls, end frames, columns and beams up to level two. (b) Placed TCC floor begin at 1st bay Level Two (c) All seismic beams installed, end walls placed

- **Step 7** Work progresses to the third level (see Figure 32(a)), where double "T" floors are placed and grouted. Repeat this step through to the fourth level (Figure 32(b)). At this stage, the constructed structure is very stable and some of the temporary bracing can be removed.

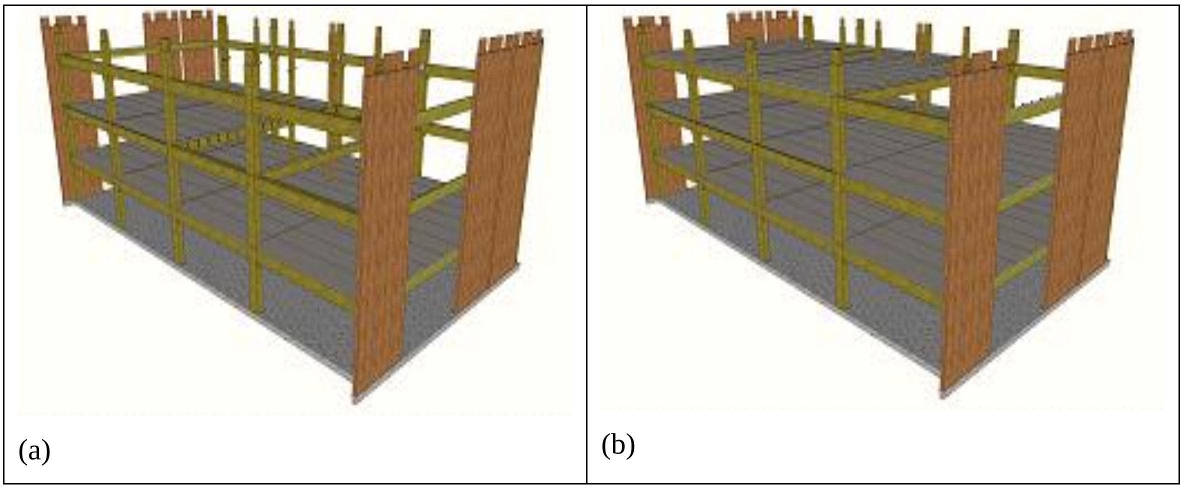


Figure 32: (a) Double "T" floor panels placed up to third level (b) Double "T" floor panels placed up to forth level.

The erection sequence for the second three storeys of the timber building is outlined in the following steps:

- **Step 8** Level four would serve as the working platform for the construction of the second three storeys (Figure 32(a)). Walls, end frames and columns are spliced at this level. Walls and column members were spliced together with 'tongue and groove' connections and bolted together. Refer to the wall and column splice connection details in Section 6.3.5. Construction work proceeds as per the same sequence as the lower storeys, working from the east to west direction (Figure 33(b)).

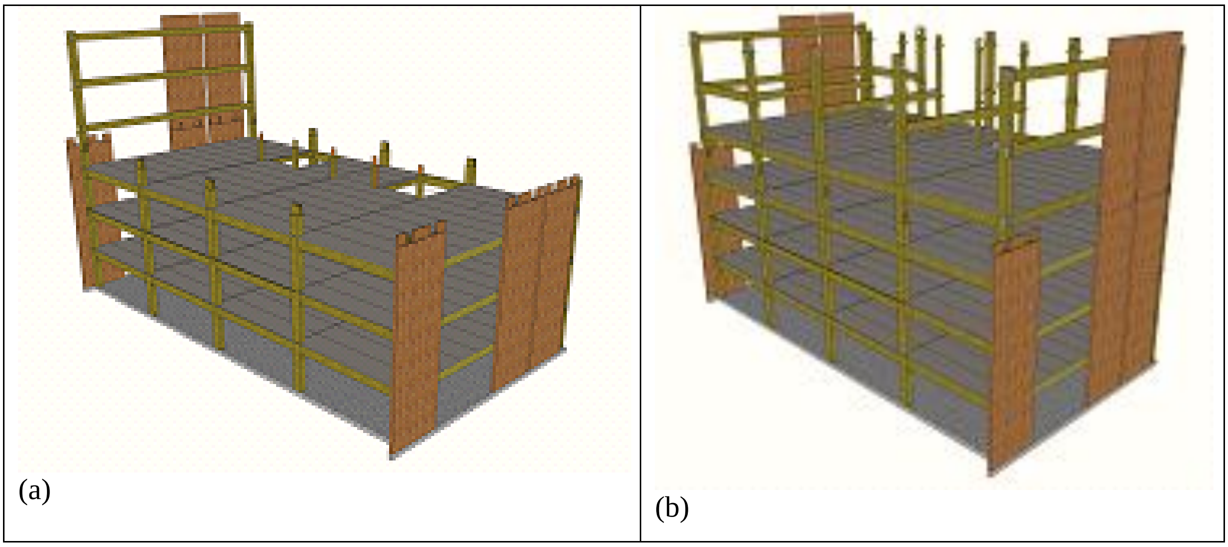


Figure 33: (a) End walls and frames in place (b) Second three storey walls and frame in place.

- **Step 9** As the work progresses further, the double "T" floor panels are placed up to the roof level, and the erection of the Pres-lam system is completed (Figure 34). The next step is to install the roof portal truss for the plant room at the roof level. All architectural fit outs, mechanical, electrical and others services work continue to progress as planned.

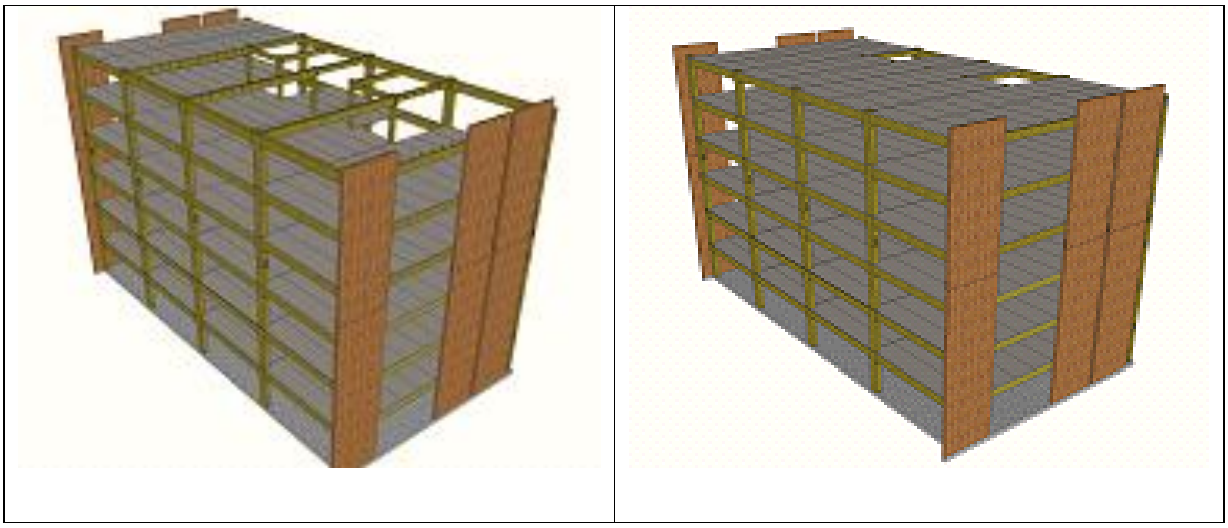


Figure 34: Double "T" floor panels are placed at roof level.

In order to understand further how this building is constructed using the above described construction method, a construction video for this Pres-Lam building has been produced. To view this video please goes to Appendix 4 for a link to the video.

6.3 Connection Details

LVL is relatively weak in compression perpendicular to the grain. In order for this engineered wood product to be used as the alternative construction building materials, the design of the connections in this system must be ductile. The Pres-Lam system was in fact based on the innovative U.S. “PRESSS” jointed ductile connection principle. The followings section will describe the connection details for: Column to Foundation Connection; Wall to Foundation Connection; Beam-Column Connection; Post-Tensioning Anchorages and Wall and Column Splicing Connection.

6.3.1 Column to Foundation Connection

The base connection of the column and wall is a movement resisting connection, similar to details shown in previous research with minor modifications to improve efficiency. Six- Ø25 mm mild steel reinforcing bars (internal energy dissipation) are embedded 400 mm into the base of column (According to NZS3603:1999). The cost effective mild steel bars with couplers were used for ease of transportation. According to Smith (2008), these provide hysteric damping and tensile strength. Alternatively a pinned connection could be used, but this would reduce slightly the strength of the frame. The size of the columns is 700 mm $\times$ 450 mm. The hold down bolts for the base connection and the Reidbar™ grout sleeves are cast in the slab or foundation beams depending on the anchorage length (Figure 35). The steel shoe for the base attachment is attached to the hold down bolts once the concrete cures. For good practice waterproof membranes are placed in between the steel plate and the base of the LVL to separate the materials from moisture.

Reinforcement bars are connected with treaded coupler mechanisms (TCM) at the base during fabrication. A low viscosity epoxy should be used to ensure full bonding, as suggested by Smith (2008). During erection the mild steel bars at the base of the wall are screwed into the couplers, and then placed into the sleeves provided in the concrete base. It is recommended the grout sleeves are filled with a recommended grout before lowering the columns into position. Alternatively the grout sleeves could be grouted once the columns were in place. The followings approved grout are recommended: Fosroc Combexta GP, Sika grout 212 and MBT 830.

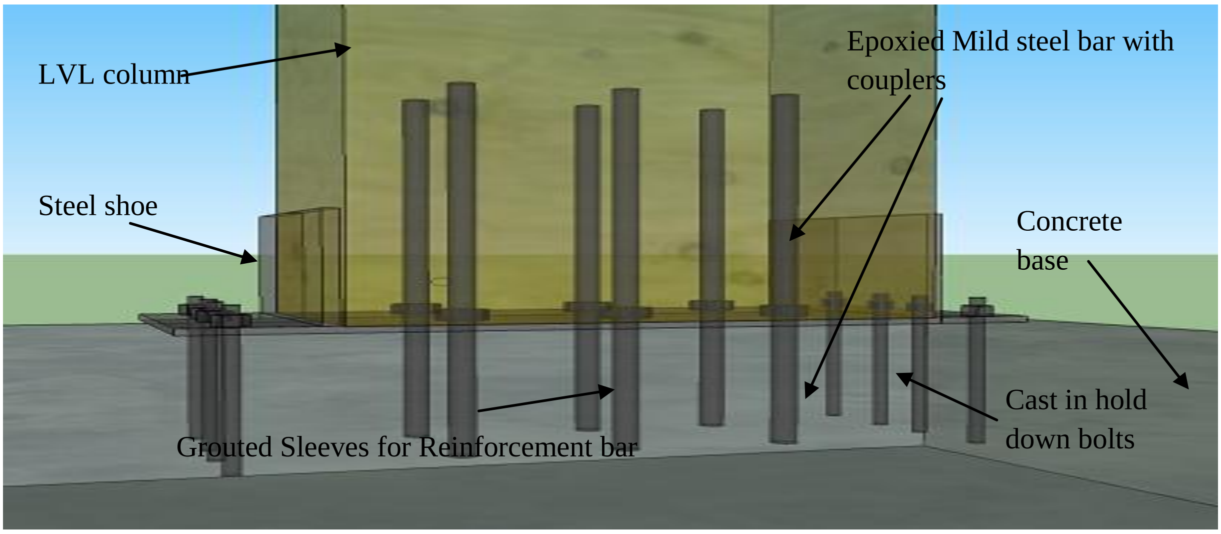


Figure 35: Moment resisting Column base connection details

6.3.2 Wall to Foundation Connection

The size of the walls is 4000 mm wide × 252 mm depth. Similar to the column base connection details (see Figure 36 to Figure 38), hold down bolts are anchored, fixed and cast in the concrete base. The Ø 32 mm and 500 mm long expoxied mild steel reinforcing bars were used. It was suggested by Buchanan (2007) that these bars should be staggered to ensure that the group failure of the connection does not occur when the largest amount of timber possible would be in tension. Waterproof membranes were also used to separate the materials from moisture.

The erection sequence is similar to the columns except the walls are post–tensioned to provide bracing for the building. This post-tensioned design used the following specifications: 12-12.7 mm P.T. tendons with unbonded length and characteristic yield strength of 1560 MPa were replaced by MacAlloy 1030 post-tensioning bars. This type of bar is a high strength deformed bar (characteristic yield strength of 1030 MPa) with hot rolled deformations especially designed to provide a serviceable thread along its full length. MacAlloy bar is available from Ø25 mm to Ø75mm, with bar lengths of up to 17.8m available for Ø25 to Ø50 and up to 8.4m for Ø 75. However, this bar is not locally available, they need to be ordered from UK which can take up to 15 weeks to arrive in New Zealand. Locally available high strength Reidbars are not used because it has lower characteristic yield strength of 500 MPa as compared to MacAlloy 1030 bars. The wall has two hollow cavities of 600 mm × 126 mm allow for post-tensioning tendons or MacAlloy bars, created during LVL fabrication. Each cavity would contain 3- Ø32mm MacAlloy 1030 bars. The full lengths of these bars were placed and tightened with nuts on bearing plates at the top of the wall panel before the panel was lifted up into position. At the base of the wall, there were two removable panels (see Figure 37). These openings allow the MacAlloy bars to be connected with the couplers during erection.

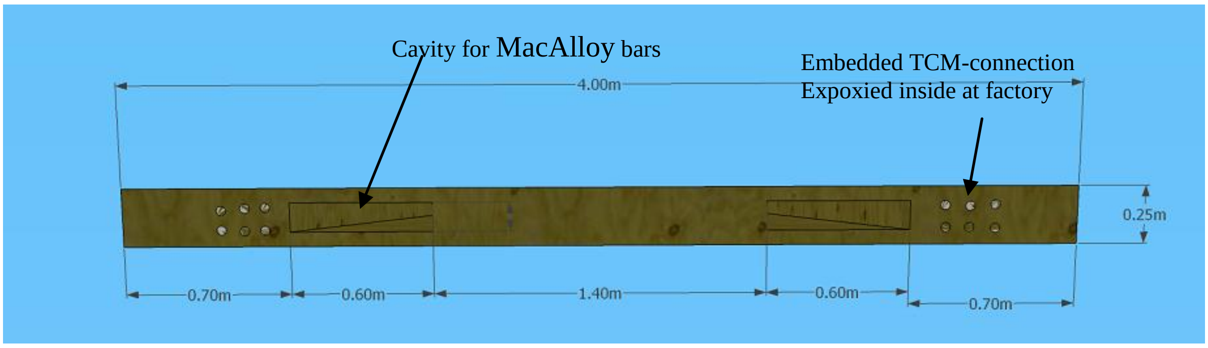


Figure 36: Bottom view of the wall panel.

These couplers connecting MacAlloy bars are anchored in the concrete base. The opening at the base of the wall would be recapped with the original LVL cut-off and then secured with screws for protecting the tendons against fire. The sleeves for the reinforcement bars at the base of the wall would be grouted once the walls are in place.

Figure 37: Similar type of Couplers system used in NMIT Project, Nelson, New Zealand.

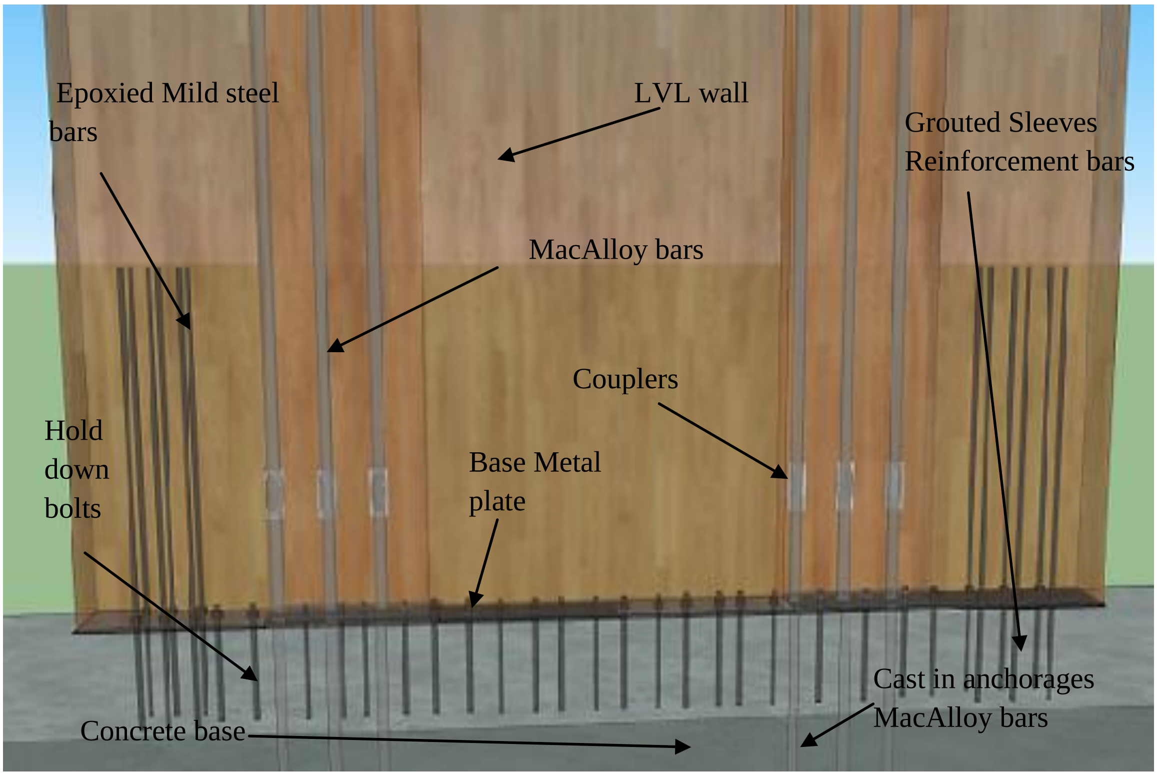
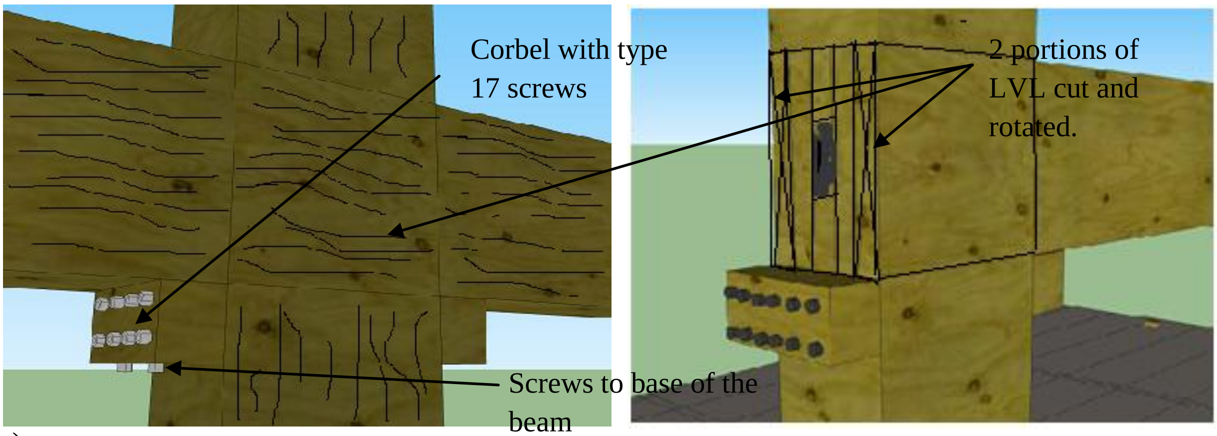


Figure 38: Moment resisting wall base connection details

6.3.3 Beam-Column Connection

Smith (2008) designed and tested a steel pre-bent angle corbel, a straight steel angle corbel and an LVL corbel. The corbels are used to carry gravity loading according to NZS3603 (1999). Providing corbels would also help to ease construction because corbels act as reference points for locating and supporting beams before post-tensioning. LVL corbels could be fabricated from left over LVL materials during fabrication, thereby reducing waste. Hence, LVL corbels were used instead of steel corbels since they are more cost effective. Corbels are glued and fastened to the columns with 14- Ø10, 175 mm long Type 17 screws. Size of the timber corbel is 450 mm wide ×100 mm high × 90 mm thick.

Immediately after the beams are placed on the corbels, screws are inserted through the corbels into the base of the beams, holding them in position until post-tensioning. During post-tensioning of the frame, high compressive forces were applied to the column perpendicular to the grain. LVL is weak in compression perpendicular to the grain. Many alternative methods to improve timber beam-column connections have been considered and tested at the University of Canterbury. For further details, refer to (Newcombe, 2010) WCTE paper. According to Newcombe (2010), the previously proposed steel armouring connection detail is expensive. An optimised beam-column design has been proposed (see Figure 39(a) and Figure 39(b)). Two external portions of LVL are cut off, rotated 90 °degrees so they are perpendicular to the grain of the column or parallel to the grain of the beam and were glued in position during fabrication. The rotated timber increases the shear stiffness of the column and reduces short and long term deformation of the column joint. This is assumed to be a cost effective and high performance method to improve the stiffness of the beam-column connections.



a)

b)

Figure 39: Beam-Column connection details

6.3.4 Post-Tensioning Anchorages

Post-tensioning for the primary beams is done on site prior to erection. The post-tensioned anchorages at both ends of the beam are concealed within the beam ends to avoid complicated detailing in the column. The seismic beams of the moment resisting frames are post-tensioned once all the beam tendons are placed. Post-tensioning anchorages are used in external columns, where moment demand is less than the internal columns. Thick metal bearing plates are used to spread the perpendicular to grain loading on the LVL from post-tensioning. The post-tensioned anchorage could be placed (1) on the column face (Figure 40) or (2) recessed into the column and later sealed with a timber cap. Option (2) is ideal for fire protection of the building (Newcombe, 2010).

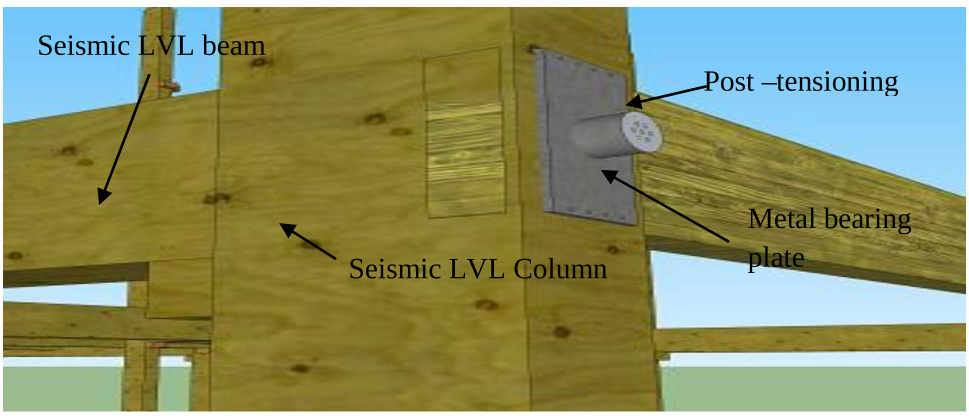


Figure 40: External Post-tensioned anchorage details in the moment resisting frame.

Because there is potential for creep deformations arising from post-tensioning the column perpendicular to grain, easily accessable post-tensioning anchorages should be used for future monitoring and maintaince.

6.3.5 Wall and Column Splicing Connection

The columns and walls would be spliced at the mid-height of fourth level. The splice was at the mid-height of the floor where the movement capacity was low for the columns. The members were joined together with "tongue and groove joints" and were then bolted transversely. The length of the tongues is 650mm for columns and walls. Bolt holes would be provided during prefabrication; three groups of 8-Ø 32 mm bolts (for wall); and 4-Ø32 mm (for column) would be use to fastened the walls and columns at splice locations. As for the walls, MacAlloy bars were connected with couplers at the splicing locations (Figure 41). The LVL cut-off would be recapped with screws.

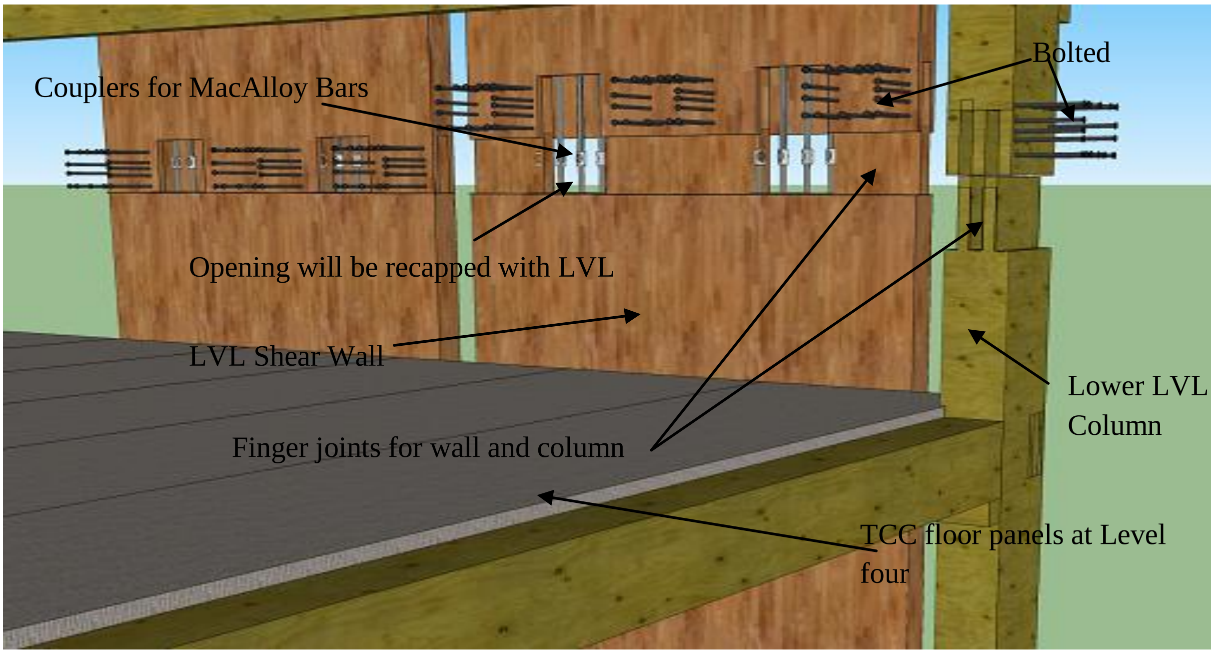


Figure 41: Splicing details for walls and columns members at mid height of Level 4.

6.4 Summary

The construction method referred to as balloon frame construction and solid LVL shear wall panels were used in the Case Study (1) virtual Pres-Lam building. A rapid erection sequence for the Case Study (1) virtual Pres-Lam building has been proposed. It is more cost effective to prefabricate LVL components as big as possible because the labour content is similar to smaller panels. The columns and walls would be spliced at the mid-span of fourth level using "tongue and groove" connections and were then bolted transversely. MacAlloy bars were used in beams and LVL walls. Connection details that will improve the constructability of the Pres-Lam system were used in the virtual Pres-Lam building.

Chapter 7: Construction Time for Case Study (1)

7.1 Introduction

The construction time required to complete a project is always an important factor for clients in the construction industry to determine the type of construction method or structural system used in the procurement of a project. Construction projects always require considerable time, effort, resources and substantial amount of financial investment to complete. The construction time of a project sometimes is determined by the owner because some owners would like a building project completed in a short time where "time is of the essence" and construction cost is secondary. Construction time is always associated with cost and this relationship between time and cost is a trade-off. However in this research this relationship will not be investigated. In order to have a fair and equal comparison, this research only used the same amount of labourers and resources for both buildings. It is the main objective of this research to identify the construction time of Pres-Lam structures to develop an optimum rapid erection process for Pres-Lam structures. Note: In the construction time analysis only the construction time of the structural building portion will be compared instead of the overall construction time of the building project. Architectural external and internal fit-outs would not be considered for all three buildings in Case Study (1).

Several alternative ways to improve the construction method or the erection sequence have been investigated prior to the development of this innovative construction sequence as described previously in Chapter 6.

To construct a building quickly, time management is very important. It is vital to know the time required for each element in each of the construction phases, as well as which activities could be carried out concurrently at different points of the schedule. The estimated time taken for the assembly of each element has been tabulated and described further below. In order to analyse the construction time, all the materials were assumed to be delivered on site "Just in Time" as according to the scheduled planned. As mentioned earlier in Section 2.2 and Section 3.4, the current fabricators of LVL are mainly cottage industries and the manufacturing process is labour intensive. Sufficient time must be allowed in the construction programme for the production of LVL prefabricated components before the commencement of actual site works. Quality assurance procedures must be setup at the factory to check all prefabricated components for straightness and tolerances prior to delivery to construction site.

7.2 Construction and Erection Time

In construction practise, the estimated time to complete an initial task (new products) would take a much longer time, but as the builders get used to the repeat tasks, the time taken to complete the task would be shortened.

A few other assumptions had to be made in order to predict the necessary time needed, these assumptions are listed below:-

- Man power during erection of the LVL system: 4 labourers, 1 crane operator and 1 rigger.
- Columns and edge beams at Grid Lines (1) and (9) would take two hours each to assemble into a frame on site and take one hour to erect.
- Column members would take half an hour to erect, plumb and prop.
- Wall members will take one hour to erect, plumb and prop after arrival on site
- Beam members (for seismic beams, edge beams, and gravity beams) would take 15 minutes to place. Primary gravity beams at Grid Lines 3, 5 and 7 needs to have the tendons placed and stressed prior to erection (one hour after arriving on site).
- Precast double “T” TCC flooring units would each take twenty minutes to place with propping not required.
- Post-tensioning tendons would be placed once the first seismic beam was installed. Allow one day to complete the task. Post tensioning works were estimated to take two hours per anchor.
- External scaffolding would be erected concurrently with the building structural system.
- Architectural external and internal fit-outs would not be considered for all three buildings in Case Study (1).
- Extra workers onsite would not be considered when evaluating the construction time.

The estimation of time taken for the assembly of the frame based on the above conservative and practical assumptions is tabulated in Table 4 as shown below.

Table 4: Assembly time for end frame use at Grid Lines (1) and (9)

Component	Unit (No)	Time (hrs/no)	Total Time (hrs)
Seismic Column	2	0.166	0.333
Edge beam	3	0.166	0.5
Attached Fasteners	6 groups	0.166	0.996
Total per frame			1.83 hrs **(2 hrs)**

There are four frames in this building and eight hours would be required to assemble the frames plus another four hours to place the frames, therefore a total of 12 hours (1.5 days) were required for the construction of the frames.

The estimation of time taken for the erection of each individual prefabricated column of the first three storeys (1st stage) of the building was based on conservative and practical assumptions as tabulated in Table 5 below. Included is the time taken to screw in the reinforcement bars at the lower end of the column base. The erection time required for the first three storeys (1st stage) of the columns was estimated to take 5.5 hours.

Table 5:- Erection for First three storeys (1st stage) of the columns

Component	Unit (No)	Time (hrs/no)	Total Time (hrs)
Seismic Column	6	0.5	3
Gravity Column	5	0.5	2.5
Total time for (1St stage) column			**5.5 hrs**

Primary gravity beams need to have the tendons placed and stressed prior to erection (1 hour after arrive on site). The time to erect a beam would be much shorter than a column because the members are much lighter (easy to handle) and propping was not required. The estimation of time taken for the erection of beams at each level is tabulated in Table 6. The estimated total erection time to place the beams at each level will take one working day.

Table 6: Total erection time for beams per floor (each level).

Component	Unit (No)	Time (hrs/no)	Total Time (hrs)
Seismic Beam	8	0.25	2
Primary beam	3	1	3
Gravity beam	3	0.25	0.75
Gravity tie beam	10	0.166	1.67
Total time per floor			7.42 hrs **(1 day)**

The estimation of time taken for the erection of each individual prefabricated wall of the first three storeys (1st stage) of the building is tabulated in Table 7. The estimated time to erect and place the wall has allowed the extra time taken to screw in the reinforcement bars at the lower end of the wall base, placement of MacAlloy 1030 bars, fasteners to edge beams, plumbing and propping were included.

Table 7: Total erection time for walls at first three storeys (1st stage).

Component	Unit (No)	Time (hrs/no)	Total Time (hrs)
Shear wall	4	1	4

Shear at gridline (A)	2	1	2
Total time walls at (1st stage)			**6 hrs**

The erection time inclusive of lifting, placing and to fasten the double “T” is shown in Table 8. The total time taken to erect double “T” floor panels per floor is estimated to be 9.5 hrs (about 1.5 working days), this is equivalent to an approximately floor coverage rate of 63m ²/hour.

Table 8: Total erection time for double “T” floor panel (per floor).

Component	Unit (No)	Time (hrs/no)	Total Time (hrs)
TCC Floor panel	38	0.25	9.5
Total time per floor			**9.5 hrs (1.5 days)**

The estimated time will be shortened as the work progresses further as the units of floor panels gradually reduce to 36 units, then 34 units as the ventilation chimneys size with floor level increases.

7.3 Comparison of Construction programmes

Based on the estimated time taken for the assembly of each element as tabulated previously (Table 4 to Table 8), the construction programme (Gantt chart) for the optimised timber building was produced using Microsoft Office Project. The estimated time is also important information to be used in the calculation to indentify the per unit rate for labour and crane usage in each activity during the construction cost estimation.

A modified concrete construction programme was produced based on Smith (2008) and the original concrete construction programme was used for comparison. The time required to complete the demolition and substructure works remained unchanged (same as concrete) in the Pres-Lam building construction programme. This was done so that a more realistic and practical comparison between the time required to build the alternative concrete Biological Sciences building. This research will not compare the steel alternative in construction time, as it is expected to remain unchanged.

The Pres-Lam building was produced based on using one tower crane, a group of five labourers; and site constraint was taken into consideration with others attributes. Figure 41 below shows the comparison of the new construction programmes for both buildings. The time required for the erection of the Pres-Lam system is 24 working days as compared to the precast concrete system that required 53 working days as shown in the very top of Figure 42. More details can be found in the construction programmes in Appendix 6 and Appendix 7. Figure 42 shows the summary of the construction programmes for the Pres-Lam building represented in green, and the solid green lines representing the duration required for the erection of LVL for the first three storeys and second three storeys, respectively. Subsequently the erections of the concrete frames were represented in solid blue lines.

Although the Pres-Lam structure could be completed 4.6 weeks or 23 working days ahead of the concrete building, it should be noted that the erection of the Pres-Lam structure only begins after 31 days (see Figure 42 to Figure 43).This is because it is a good practice to erect Pres-Lam above the ground on a completed concrete floor slab. The erection of the precast concrete building walls, frames, and floor units was completed in 83 working days and work commenced work 24 days immediately after the completion of the foundation beam along the west direction (Grid Line 1) without having to finish all other foundation beams and the ground floor concrete slab.

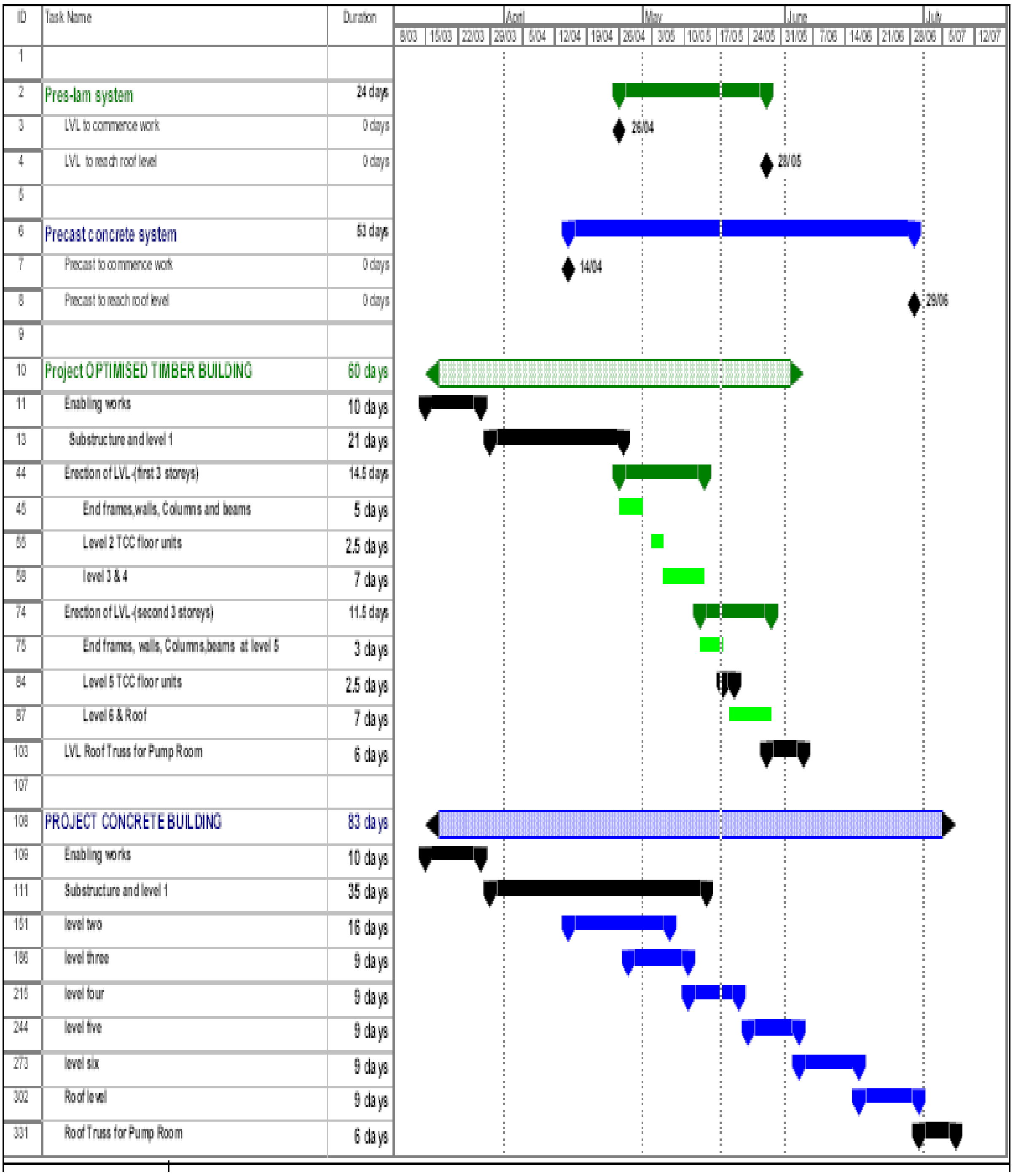


Figure 42: Summary of the Construction Programme for Both Buildings.

The comparisons of the construction sequences for the three buildings are represented graphically in Figure 43. This figure also provides an illustration of the construction time at different stages of the structural systems of the three buildings and was based on the interpretation from of the construction programmes (Gantt charts). The erection time of the Pres-Lam structure required only 60 working days (23 working days faster or about 4.6 weeks) than the simplified concrete building (83 working days).

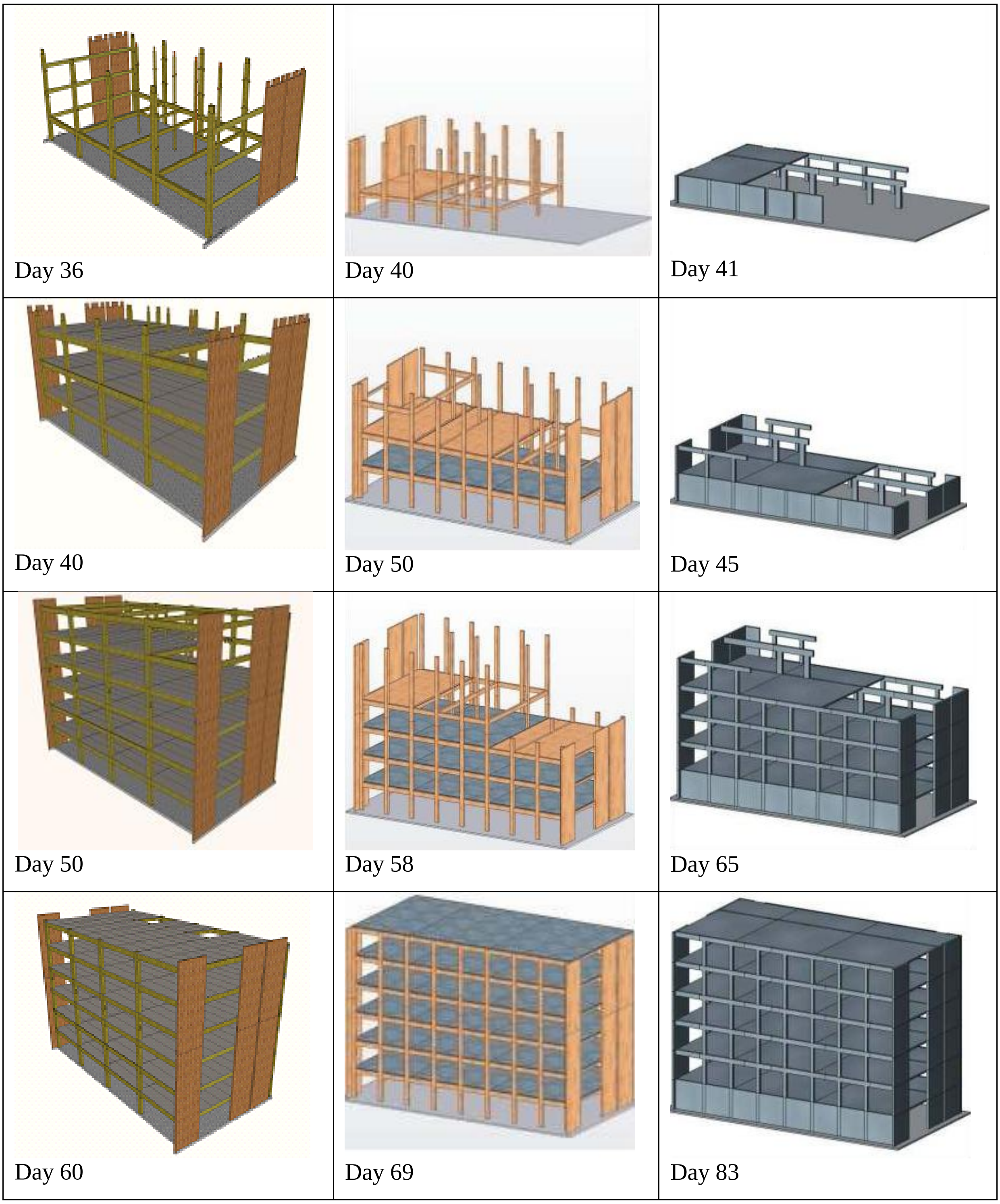


Figure 43: Structural erection time comparison- (left) Pres-Lam building (middle) source from Smith (2008) Timber building. (Right) Construction programme for concrete structural. (Revised)

The comparison of the construction programmes could be further breakdown into the required working days to complete the substructure works, structural works and roof portal frames (see Figure 44). The Pres-Lam structure only required 60 working days to complete the overall structural works. The construction to complete the roof portal frames was the same in both buildings. It was noted that there was a significant different in substructure works, where the Pres-Lam structure needed 30 working days (contributed 50 percent of its time spent in enabling, substructure and Level (1) in-situ works as compared with concrete of 23 days (contributed 29 % of the time). However, the Pres-Lam structure required a very short duration of 24 working days or equivalent to the average rate of 4 working days per floor as compared to the concrete building requiring 53 working days (8.8 working days per floor). The Pres-Lam structure has a huge reduction in construction time as compared with the concrete building.

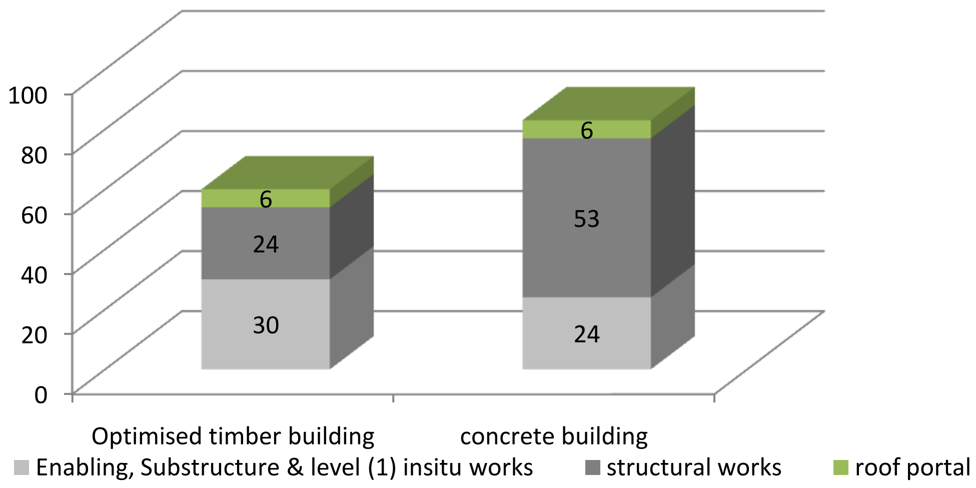


Figure 44: Construction Time Comparison Chart for both buildings in working days.

In the construction time analysis only the construction time of the structural building portion was compared instead of the overall construction time of the building project. However it was expected to have the same outcome as the construction time assumes completing all the architectural fit-out works, electrical works, sanitary and plumbing works, HVAC services and many other works for both buildings would require the same duration. However it should be noted that based on experience, the time required for fixing cladding, ceilings, electrical services and plumbing work on a timber building was much less.

7.4 Comments and Feedback from Independent Professional Project Manager

Upon the completion of the Gantt charts construction programmes, copies of the new optimised LVL timber and the concrete construction programmes were sent to an independent professional project manager to review and comment. To ensure a high standard of work was achieved for the research, it was necessary to seek advice from an independent professional project manager (PM) in the construction industry to review the construction programmes. Three companies were chosen to review the construction programmes, they were:

- Arrow International Ltd, a professional project management company, was chosen to review the construction programmes because of its knowledge from previous involvement in the Smith (2008) research. They are also the project manager for the NMIT building project currently under construction.
- Mainzeal Contractors Ltd was chosen to review the construction programmes because of its knowledge from their pervious involvement in the 2/3 scale experimental building.
- C. Lund & Son Ltd. was chosen to review the construction programmes because it is the contractor for the actual Biological Sciences building currently under construction (2008-2010).

The comments and feedback from the project manager Mr. Graeme Jones from Arrow International Ltd. were that he agreed with the planning in the Pres-Lam construction programme. He also stressed that the construction programmes was done in a very practical and realistic manner. However, Mr Jones agreed that the previous concrete construction programme needed to be revised because the programme had incorporated multiple tasks running concurrently and overlapping each other at one time. This was only possible if excessive resources such as large group of labourers, extra cranes and machinery were allocated to do the work. The actual site constraints have not been considered. The new construction programme showing that the overall construction time of Pres-Lam structure requires only 60 working days, was possible. However he also stressed that to achieve that speed of construction time, sufficient covered storage space for the prefabricated LVL components needed to be provided to ensure that no shortage of materials occurred during construction.

Two important questions were given to Mr. Andrew Macgregor from C. Lund & Son Ltd. If the "virtual simplified" Biological Sciences concrete building was going to be build by C. Lund & Son Ltd.:

- What would be the construction sequence? and
- What is the construction time required to build the concrete building from the foundation to roof truss, excluding all the architectural fit-out and M & E works?

Mr. Macgregor stressed that "The 9 days per floor cycle for the concrete building is the optimum that can be allowed, any time less then that is not achievable". He commented that

the concrete and optimise timber construction programmes compared well as both programmes assumed “ideal situations” and they were carried out in a very practical and realistic manner.
In addition, according to Mr. Ross Copland from Mainzeal Construction Ltd., the construction programme for the timber building is achievable based on his experience with the Pres-Lam construction.

7.5 Key Factors that have contributed to the Rapid Construction of the Pres-Lam Structure

The key factors that have contributed to the rapid construction of the Pres-Lam structure are as follows:

1. The Pres-Lam structural system is primarily prefabricated and consisted of the columns, beams, walls and double “T” floor system. Hence this eliminated the on-site concrete pour which is less time and cost effective.
2. The prefabricated elements come in standard sizes. So this contains identical or repetitive units that can ease production as well as construction.
3. Balloon construction method was used due to the lightweight of LVL prefabricated components.
4. At Gird Lines (1) and (9), columns and edge beams were assembled onto frames on the ground to ease the construction time.
5. Since it is a Pres-Lam structure, larger spans of prefabricated beams and floor panels have been achieved.
6. Overall the total quantity of prefabricated components also has been reduced by 44 tonnes (excluding LVL floor joists).
7. The pre-cambering of the double “T” floor panels at the factory have removed the need of propping to the floor which is less time and cost effective.
8. MacAlloy 1030 bars were used for the LVL shear walls panels.
9. The simplicity of all the connections and the lightness of the LVL prefabricated components have eased manoeuvrability and have increased the overall constructability of the Pres-Lam structural system (Newcombe, 2010).

7.6 Summary

In the construction time analysis only the construction time of the structural building portion was compared instead of the overall construction time of the building project. Overall the optimised building was 38 percent more efficient than the concrete building in terms of structural construction time. This has suggested that the Pres-Lam structural system is much faster as compared with similar concrete structural systems. Therefore by using the time efficient Pres-Lam system in construction, it is possible that the reductions in construction time could be realised. Building owners could occupy their building in a much shorter period, hence a much earlier return on their investment could be achieved.

Chapter 8: Construction Cost

The construction cost estimate of a new structural system is usually difficult to carry out. Initially, the contractors involved will normally allow a higher contingency sum in order to take into account the potential unknown risks associated with the construction project. As the structural system becomes more commonly used over time, the construction industry is more receptive to the structural system, which leads to a reduction in associated risk. Once the construction cost of the Pres-Lam system is better known, the construction cost will be easier to estimate and the construction time and cost associated will reduce.

8.1 The Cost Estimation Plan

In Chapter 7, a comparison was made between the difference in structural construction time for the optimised Pres-Lam and concrete buildings. It was then compared with Smith's (2008) timber building. The construction time of the steel building was expected to remain unchanged, therefore, no comparison was carried out. This chapter will compare the difference in construction cost, including claddings and architectural fittings, between the three buildings; optimised Pres-Lam, concrete and steel. In order to make the comparison more valuable, other factors such as cladding, roofing, and other services are considered to obtain a complete construction cost comparison. The cost estimate was based on the architectural and structural drawings, and designs received from previous and recent UC researchers (Nicholas Peres, Tobias Smith, Stephen Liong, Michael Newcombe and David Yeoh).

The construction method used for a project must be identified first prior to preparing the cost estimation. By understanding the estimated time required to complete each task, per unit rates for labour and other related costs can be determined (Sears, 2008). The next step was the preparation of the quantity survey of the building project. This survey was a detailed compilation of the nature and quantity of each work type required. Taking off quantities was done in substantial detail, with the building being divided into many different work types (Sears, 2008). Construction cost estimation was carried out from the data provided and quotations received by the LVL suppliers, fabricators, contractors from the completed 2/3 scale experimental building (Newcombe, 2010), as well as referencing to the Rawlinsons Construction Handbook (2009).

To ensure a high standard of work was achieved for the research, it was necessary to seek advice from an independent professional quantity surveyor (QS) in the construction industry to review the cost estimation. Davis Langdon Shipston Davies QS Consultancy was chosen to review the costing because of their knowledge from previous involvement in the Smith (2008) research. They are also the QS consultant for the Biological Sciences building, as well as the NMIT building project currently under construction. The new cost estimation of the project was presented to the QS for review, comments and feedback. A field interview was conducted with the QS to identify the actual cost of construction for concrete, steel and Pres-Lam for the projects.

8.2 Comparison to the Changes in Quantity and Sizes

The main advantage of the Pres-Lam system is that utilising post-tensioning cables in the beams can achieve greater bay width when compared with concrete buildings. The Pres-Lam system allowed the optimised structural redesign to maximise the single bay width to a double bay width. The followings are the changes for the optimised Pres-Lam building:

- The numbers of columns have reduced from 18 to 10 in the seismic frame system due to this optimisation.
- With the increased column spacing, seismic beam length has changed from 3770 mm to approximately an 8 metre span.
- The column and beam sizes have increased from (600 mm × 378 mm) to (700 mm × 450 mm) by reducing the numbers of columns in the optimised redesign process.

Table 9 show the details of the changes for the member sizes of LVL. From the comparisons in Table 9, the total quantity of LVL Smith (2008) used in the timber structural frames and walls was 340 cubic metres and 146 cubic metres respectively. The total quantities of LVL used in the optimised timber structural frames and walls were 259 cubic metres and 146 cubic metres respectively. It should be noted that the above quantities excluded the double "T" floor joists. Overall, the optimisation process in the timber structural frames, which removed every second column to increase the bay width, provided a 44 cubic metre (24 tonne) reduction of LVL.

Table 9: Comparison of Smith (2008) timber building LVL member sizes with the optimised timber building.

Member	Smith (2008) Timber Design			Optimise Timber Design		
LVL	**Dimension (mm)**	**Length (mm)**	**Quantity**	**Dimension (mm)**	**Length (mm)**	**Quantity**
Beam (L2 to L5)	600 × 378	3762 & 3770	64	700 × 450	7982 & 8024	32
Beam (L6 to Roof)	600 × 378	3762 & 3770	32	700 × 270	7982 & 8024	16
Primary beam	600 × 378	11772	24	600 × 396	11525	18
Gravity beam	450 × 378	5572	24	450 × 378	5550	30
Tie beam	240 × 126	3562	22	240 × 126	3562	12
Edge beam	600 ×189	17600	12	600 ×189	18400	12
Cantilever beam	200 × 189	2200	36	200 × 189	2200	36
Plant room portals	360 ×189		161m length	360 × 189		161m length
Column-gravity	500 × 378	11430	4	400 × 378	11430	5
Column-Seismic	600 × 378	11430	18	700 × 450	11430	10
Slender column at GL C	200 × 189	3610	6	200 × 189	3610	6
Wall (L1-L4)	4000 × 252	11430	6	4000 × 252	11930	6
Wall (L4-Roof)	4000 × 252	12430	6	4000 × 252	11930	6
Total prefabricated elements (units)			254	Total prefabricated elements (units)		157
Total quantity			**485** (m^3)	Total quantity		**441** (m^3)

Optimising the bay width has also led to a significant increase in the quantity of the post-tensioning of the optimised timber building. Table 10 shows the comparison between the sizes of the post-tensioning tendons and anchorage for the optimised timber building with the Smith (2008) timber building. All post-tensioning used size 0.6" or 14.7mm diameter 7-wire strands. The previous research for the timber building did not show the quantities and the costing of the post-tensioning works.

Table 10: A comparison between the post-tensioning designs of the optimised Pres-Lam building with the Smith (2008) timber building

Post tensioning	**New Optimised Design**	**Smith (2008) Timber Design**
Beam (L2-L3)	2×9- 12.7 mm Tendons-(5-12 VSL Anchorage)	12-12.7 mm Tendons -(5-12 VSL anchorage)
Beam (L4-L5)	2×8 -12.7 mm Tendons-(5-12 VSL Anchorage)	7-12.7 mm Tendons -(5-7 VSL anchorage)
Beam (L6-Roof)	1×10-12.7 mm Tendons (6-12 VSL Anchorage)	3-12.7 mm Tendons (5-3 VSL anchorage)
Primary Beam	19-12.7 mm (5-19 VSL anchorage)	19-12.7 mm (5-19 VSL anchorage)
Wall	Used 32mm MacAlloy 500 bars or 12-12.7 mm 0.5' Tendons (5-7 VSL anchorage)	12-12.7 mm Tendons (5-7 VSL anchorage)

Previous research calculated the total gross floor area for the semi-prefabricated TCC floor units to be 4304 m^2 based on preliminary estimation. A more detailed analysis, which takes into account the area of the ventilation chimneys, shows that the new optimised double "T" floor panels is 3616 m^2 (see Table 12). The above cost estimate will have a reduction of 690 m^2 in floor area for this research.

Table 11: Sizes and quantities of the Smith (2008) TCC floor system

Smith (2008) Timber Design				
Floor system	**M ember size (mm)**	**Span (mm)**	**Width (mm)**	**Nos. of panels**
Semi-prefabricated TCC floor system (m-section) 400 x 63mm LVL @ 1200mm centres with 17mm plywood, 65mm cast in-situ concrete topping, and square cut notches with M10 coach screws.	$2\times(1\times 400\times$ 63mm) + $(2\times 400\times$ 63mm)	A1-8654 A2-8346 A3-3984	B1-2400 B2-2400 B3-2400	90 45 62
Total floor area =(A1B1+A2B2+A3B3)= **3621m ^{2}**				
Total 17mm plywood required= **4304** square meters				197 units
Total length of LVL floor joist (400×63mm)		**5605 m** (approx=142 cubic metres)		

Table 12: Sizes and quantities of the Double "T" TCC floor system

<table>
<tr><th colspan="5">Fully prefabricated Double “T”</th></tr>
<tr><td>Double “T” floor -400 ×(2 ×63) LVL double joists @ 900mm centres with 75mm precast concrete and toothed metal plate’s connection.</td><td>2×(2 ×400 × 63mm)</td><td>A1-8645
A2-8328
A3-3966</td><td>B1-1800
B2-1800
B3-1800</td><td>120
92
28</td></tr>
<tr><td colspan="5">Total floor area =(A1B1+A2B2+A3B3)= 3616 m ²</td></tr>
<tr><td colspan="4">Total 17mm plywood required= NIL</td><td>240 units</td></tr>
<tr><td colspan="3">Total length of LVL floor double joists (400 × 2x63mm)</td><td colspan="2">7658 m (approx=193 cubic metres)</td></tr>
</table>

Due to the optimisation of the floor design in this research, the quantity of floor panels has increased to 240 units, compared to Smith’s (2008) timber building having 197 units. In this research, the quantity of the LVL floor joists also increased to 195 cubic metres, compared to Smith with 145 cubic metres. There are many advantages of utilising the double “T” floor system, such as substantial reduction in the construction time and construction cost, by:

1. Eliminating the 17mm thick plywood (permanent formwork) from the TCC floor system that was developed in UC.
2. Eliminating the labour intensive fabrication of cutting the notches on the LVL floor joists.
3. Eliminating the use of the specially prefabricated floor joist hangers on site.
4. Elimination of the on-site concrete pouring, the propping of the floor system and ease of prefabrication at factory.

Overall it is a more time efficient floor system.

8.3 Comparison Cost Analysis

The unit rates for the Case Study (1) Pres-Lam building were produced based on the following:

- These unit costs are extrapolated forward in time to reflect current market conditions, project location, and the particular character of the Case Study (1) research building.
- By referencing the UC experimental building and with some consideration to the Case Study (1) building. If the internal plates in the column are not used for the complicated beam column joints, and external bars (energy dissipaters) are removed, the construction cost of a basic LVL frame (delivered and in place) should be in the range of $2900/m^3 to $3000/m^3. These prices exclude the cost of the base connection and post-tensioning works.
- By referencing current data obtained from Menendez (2010) for the estimated cost, the semi-prefabricated TCC floor system is $245/m^2, and the shear wall is approximately $3200/m^3.
- The estimated construction (delivered and in place) cost for the double "T" floor system is $265.00/m^2.
- The above established unit rates are based on the current LVL material cost of $1400/m^3 and the fabrication cost of $1000/m^3, also by referencing to the Giddens (2009) Rawlinson's Construction Handbook.

With the above available cost information, the construction cost estimations for the buildings were produced. The construction cost estimates were reviewed with the related QS in a field interview. Mr. Phil Schumacher (Davis Langdon Shipston Davis) has reviewed and agreed with the LVL rates used, and he also updated the rates used in the estimates. According to Mr. Schumacher, "They are now all in today's dollars. As discussed in our meeting the major changes came in the concrete and reinforcing rates, and also the contractor margin has reduced from 15% to 13 %. So we have adjusted all these to suit. I have checked the LVL rates used, and they look to be very similar to those priced on NMIT Arts and Media Building".

8.3.1 Comparison Cost between the Buildings

The cost comparison between the optimised Pres-Lam building and Smith's (2008) building is evaluated to be as follows:

- Smith (2008) estimated the construction cost for the structural frames to be $1,319,000. This was then divided by the 340 cubic metres of LVL, equating it to be $3880/m^3.
- The construction cost for the Pres-Lam structural frames (inclusive PT works) was to be $926,000, and was then divided by the 259 cubic metres of LVL, equating it to be $3,577/m^3.
- The cost saving in structural frames alone, compared with the previous research, equates to $426,642 with a saving of $302/m^3 or a reduction of 8 %. The estimated Post-tensioning works to the seismic frame were $130 per cubic metre of LVL.
- The design of the LVL walls remained unchanged as compared with Smith (2008). However, the construction cost for the structural walls of the Pres-Lam was $4245/m^3. The cost saving in structural walls compared with the previous research was $48,365 with a saving of $331/m^3 or a reduction of 7 %.
- Currently the Post-tensioning works (MacAlloy 1030 bars) in terms of per cubic metre of LVL wall, cost between $330 and $350. The recent quotation for the post-tensioning was provided by Construction Techniques Ltd. and can be found in Appendix 9.

The difference of $268,603 (39%) is relatively high in the upper floors between the optimised double “T” floor system and Smith’s (2008) semi-prefabricated TCC floor system. This is because the construction cost for the optimised double “T” floor system was estimated to be approximately $265/m^2. Key factors that contributed to the difference were:

1. In Smith (2008) the estimated the floor system was $160/ m^2; the cost of the in-situ concrete topping had not been included. This was verified by Mr. Schumacher, the QS from David Langdon Shipston Davies.
2. Newcombe (2010) used a much smaller version of the same floor system for the experimental building and has identified the construction cost to be $216/m^2.
3. Menendez, J.M. (2010) estimated the semi-prefabricated TCC floor system to approximately $245/m^2 for his case study building in Napier.

The estimate summary for the comparison of the main elements of the buildings is shown in Table 13 (For further details such as the breakdown of each items see Appendix 3).

Table 13: Construction cost (NZ $) estimates comparison between the three buildings and Smith's (2008) Timber Building, Revised.

Element	Pres-Lam Building-(2010)	Concrete Building-(2010)	Steel Building (2010)	Smith (2008) Timber Building (revised)
SUBSTRUCTURE	228,920	230,890	231,550	215,920
FRAME	892,524	752,318	1,628,917	1,319,166
STRUCTURA-LIFT SHAFT WALLS	Included in above (frame)	136,110	Included in above (frame)	Included in above (frame)
FRAME POST-TENSIONING WORKS	34,089	nil	Nil	Assume ADDED TO FRAME
UPPER FLOORS	957,243	723,550	645,600	688,640
ROOF	169,915	169,915	169,915	157,330
EXTERNAL WALLS & EXTERIOR FINISH	619,785 493,845	1,053,510	428,595	668,150 386670
WINDOW AND EXTERIOR DOORS	1,017,850	1,017,850	1,017,850	945,200
STAIRS AND BALUSTRADES	54,000	72,900	72,900	54,000
INTERIOR WALLS	563,500	460,120	539,775	528,160
INTERIOR DOORS	68,200	68,200	68,200	68,200
FLOOR FINISHES	361,380	361,380	361,380	361,380
CEILING FINISHES	249,250	249,250	249,250	230,950
SANITARY PLUMBING	74,600	74,600	74,600	67,400
HEATING AND VENTILATION SERVICES	1,382,700	1,382,700	1,382,700	1,382,700
FIRE SERVICES	345,675	345,675	345,675	345,675
ELECTRICAL SERVICES	599,170	599,170	599,170	599,170
LIFT	200,000	200,000	200,000	200,000
SPECIAL SERVICES	50,000	50,000	50,000	50,000
DRAINAGE	50,000	50,000	50,000	50,000
EXTERNAL WORKS	4,840	4,840	4,840	4,840
SUNDRIES	450,480	450,480	450,480	446,800
	8,867,967	**8,453,458**	**8,571,397**	**8,870351**
PRELIMINARIES & MARGIN (13%)	1,152,835	1,098,949	1,114,281	**(15%)** 1,330,552
GRAND TOTAL	**$ 10,020,802**	**$ 9,552,407**	**$ 9,685,678**	**$ 10,200,903**

8.3.2 Difference in Cost between the Structural Frames

This section discusses the comparison between the Pres-Lam, concrete and steel buildings. Table (14) and Figure (45) provide a clear comparison between the three structural systems. These are significant differences and represent the overall cost differences between all the buildings. The comparison of the difference in cost between the substructures of the three buildings is similar to the Pres-Lam system. However, the Pres-Lam system is estimated to be slightly lower by $2,000. For the comparison of the difference in cost between the structural frames of the three buildings estimated the steel building is the highest at $1,628,917. Followed by the Pres-Lam building at $ 926,613 (inclusive PT works) while the concrete building is the lowest at $888,428. The structural steel frame is the highest due to the high price of steel components.

In terms of the external walls and external finishes, the Pres-Lam system is $60,120 or 5.7% more than the concrete building. In terms of external walls and finishes, the steel building is the cheapest option at only 38% of the cost for the Pres-Lam building external walls and external finishes (see Table 14).

Table 14: Comparison of the structural elements of the three buildings

Element	Pres-Lam	Concrete	Steel
Substructure	$ 228,920.00	$ 230,890.00	$ 231,550.00
Structural Frames	$ 926,613.00	$ 888,428.00	$ 1,628,917.00
External walls & finishes	$ 1,113,630.00	$ 1,053,510.00	$ 428,595.00
Upper floors	$ 957,243.00	$ 723,550.00	$ 645,600.00
Roof	$ 169,915.00	$ 169,915.00	$ 169,915.00
Total structural system	**$ 3,396,321**	**$ 3,066,293**	**$ 3,104,577**

Comparing the difference in cost between the floors systems, the optimised double “T” TCC floor system used in the Pres-Lam building is the highest at about 3% more than the concrete building using Dycore and Unipsan floor system. The Comflor 80 floor system used in the steel building is the cheapest. The roof system for the three buildings is the same.

Others costs for architectural elements such as windows and exterior doors; interior walls and doors; floor and ceiling finishes; stairs and balustrades; fire protection; electrical and plumbing services; heating and ventilation; lifts; drainage and external works; and sundries are similar.

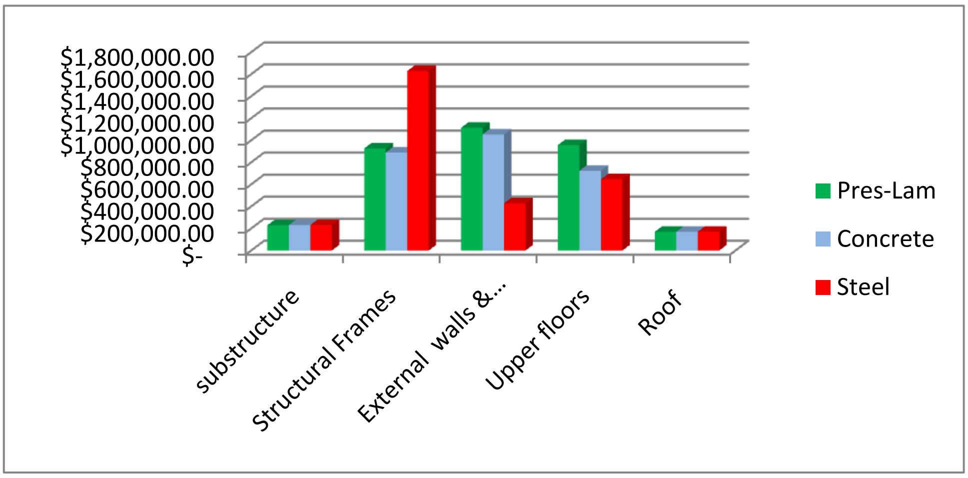


Figure 45: Comparison of structural elements cost of the three buildings

8.3.3 Delivered and in Place Cost for Pres-Lam System

Overall, the structural system for the Pres-Lam building consisted of the substructure LVL frames, LVL walls (excluded external finishes), double “T” floor units and roof truss system which contributed 34% ($ 3,396,321) of the grand total construction cost of the building (as shown in Table 13 and Table 14). The construction cost (delivered and in place) for the Pres-Lam building can be further broken down into the individual structural elements. The use of the fully prefabricated double “T” TCC floor system was $957,243 (33%) of the delivered and in place cost. It is the biggest portion of the delivered and in place cost. As for the Dycore and the Unispan floor systems used in the concrete building, the prices are in the range of $130/m ^{2}to $180/m ^{2}which only contributed 23% to the structural system cost. Comparatively, the Comflor 80 floor system with the 150mm concrete topping is $150/m ^{2} and contributed only 20% to the steel structural system.

The cost of the double “T” TCC floor system could be further broken down for analysis. The material (LVL) and fabrication are relatively high cost and contributed 60% to the delivered cost, and the prefabrication of the concrete topping is 25% of the total cost of the floor units (see Appendix 3). Currently the fully prefabricated double “T” TCC floor system is still not the most cost competitive floor systems available.

The LVL frames are 31% of the delivered and in place cost. This is highly competitive, and compares well with concrete and is also much lower than the steel structural system (as described in Section 8.3.2 and Figure 45 and Figure 46. The LVL wall system (includes PT works) contributed to 21% of the total delivered and in place cost for the structural system. Post-tensioning contributed 1% to the total delivered and in place cost for the structural system.

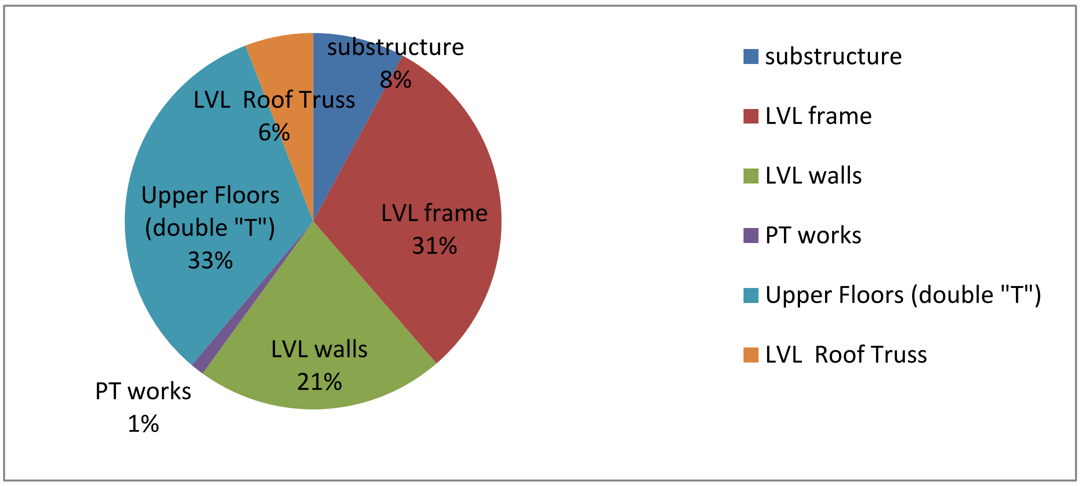


Figure 46: Delivered and in place cost for Pres-Lam building

8.3.4 Comparative of Construction Costs for the Buildings

Table 15 indicates that the Pres-Lam building has a $180,101 (1.8%) price reduction as compared with the previous Smith (2008) timber building. The savings are expecting to be higher from the optimisation, and with the current recession, there has been a reduction in the construction (Preliminaries and Margin) from the previous year of 15% to current 13%. However, this is not the expected outcome because of these two main reasons that have offset the differences:

1. The costing done by Smith (2008) in 2007 needed to be multiplied by 3 years inflation factor that has led to the increase in today's price.
2. Building materials prices for concrete, steel, aluminium and glasses have increased over the last 3 years.

The above increments have also led to an increase in the construction costs by $ 119,150 (1.3%) for the concrete (2010) building and by $ 297,340 (3.2%) for the steel (2010) building. The steel building has the highest increase in price in comparison with the Pres-Lam and the concrete buildings.

Table 15: Comparative of the grand total costs of the buildings

Building Material	Grand Total Construction Cost (2010)	Grand Total Construction Cost (Smith, 2008)
Pres-Lam system	$ 10,020,802	$ 10,200,903
Concrete	$ 9,552,407	$ 9,433,257
Steel	$ 9,685,678	$ 9,388,338

Figure 47 provides a graphical comparison of the total costs of the buildings in 2010 and 2008. The Pres-Lam building construction cost is currently estimated to be $ 335,124 (3.3%) more than the steel building and $ 468,395 (4.6 %) more than the concrete building (see Figure 47). This minor difference of less than ±5% is negligible, indicating that the cost of the Pres-Lam system is comparable with concrete and steel building materials.

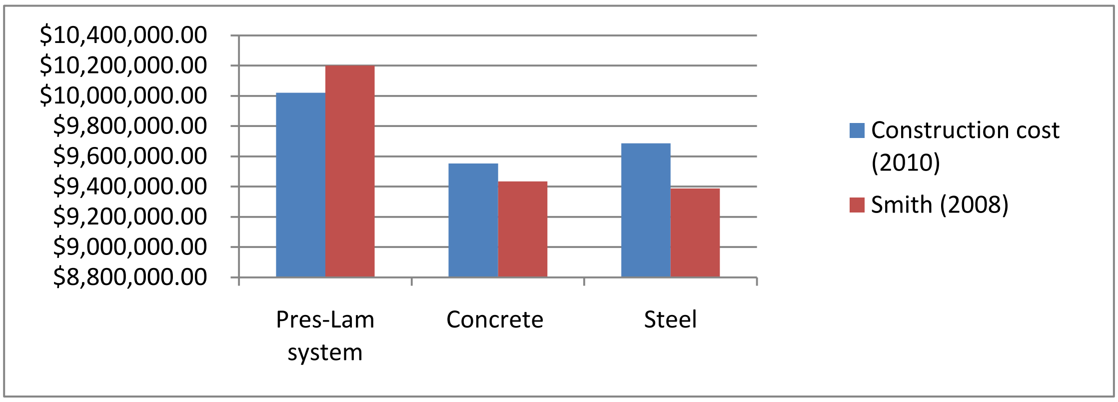


Figure 47: Comparisons of the grand total construction cost of the buildings

Table 16 summarises the identified estimated construction cost per unit rate and is current (2010) for the Pres-Lam system.

Table 16: Summary of the estimated construction cost per unit rate for Pres-lam (2010)

	LVL	Unit	Current Rates
1(a)	**LVL Frame** (columns and beams) included base connections and other fixings for delivered and in place.	m^3	$3200-$3400
1(b)	Post-tensioning works in term of per cubic metre of LVL frame (delivered and in place).	m^3	$130-$140
2(a)	**LVL walls** included paint on 9 exotec rain-screens, base connection and other fixings for delivered and in place.	m^3	$3700-$3900
2(b)	Post-tensioning (used MacAlloy 1030 bars) in term of per cubic metre of LVL wall (delivered and in place).	m^3	$330-$350
3	Fully prefabricated **double "T" floor** with 400 ×(2×63) LVL double joists @ 900mm centre. 75mm thick precast concrete with come with pressed toothed metal plate, wire-mesh and H12 reinforcements (delivered and in place).	m^2	$255-$265
4	Pres-Lam system use for commercial office building	m^2	$ 2,400

Note:

- These established unit rates are exclusive of good and service tax (GST); consultancy professional and legal fees; land accusations and demolition; parking areas and landscaping; loose furniture, fittings and equipment (FF&E); consents, and other related development expenses (These are assumed to be similar for all three buildings).
- The established building cost per square metre by using the Pres-Lam system for commercial and office buildings is identified to be approximately $ 2,400. Costs are based on the floor area of all levels, measured over all external walls. The average prices for the base building works for typical concrete buildings (for office buildings- high rise 6-15 storeys with full services) within NZ is in the cost range from $2,300 to $2750 (Rawlinson's, 2009).
- In addition to the above costs, an interesting finding from this research was that by using the different lifting capacity of a smaller tower crane for the light weight of the Pres-Lam system as compared with the concrete building, there is a cost saving of $ 68,325 in crane usage (Appendix 4).

8.4 Summary

Due to the optimisation of the Pres-Lam building, there was an $180,101 (1.8%) price reduction as compared with the previous Smith (2008) timber building. However, this is not the expected outcome because of these following reasons that have offset the differences:

1. The costing done by Smith (2008) in 2007 needed to be multiplied by 3 years inflation factor that has led to the increase in today's price.
2. Building materials prices for concrete, steel, aluminium and glasses have increased over the last 3 years.
3. During current recession, there has been a reduction in the construction preliminaries and margin from previous year of 15% to current of 13%.
4. Comparative of the grand total costs of the buildings, the percentage different between the optimised Pres-Lam building compare with Smith's (2008) Timber building is reduced by 1.8%.

The Pres-Lam building construction cost is currently estimated to be $ 335,124 (3.3%) more than the steel building and $ 468,395 (4.6 %) more than the concrete building. This minor difference of less than $\pm 5\%$ is negligible, indicating that the cost of the overall building of the Pres-Lam system is comparable with concrete and steel buildings. The established building cost per square metre by using the Pres-Lam system for commercial and office buildings is identified to be approximately \$ 2,400/m^2.

Chapter 9: Case Study (2) Deconstruction of STIC Two Storey Experimental Building

9.1 Introduction

Deconstruction and reconstruction of a building normally occurs only happen when an old building is torn down to make way for new developments or when there is a disaster where damaged buildings need to be rebuilt. Deconstruction occurs when selected parts of the building components are dismantled for reuse and recycling. This is different from demolition, where a building is cleared for other means and the material sent to a landfill. In a generation dominated with global warming and climate change issues, the demand for sustainable building is increasing and the need for buildings that can be deconstructed has grown. The Pres-Lam system has claimed to be a sustainable system and easily demounted for reuse. The sustainable building materials used in this type of building must be able to be recycled and be reused for other purpose after a completed life cycle so that only limited waste will be consigned to the landfills. This chapter will investigate deconstruction of a 2/3 scale experimental Pres-Lam building and reconstruction at a site located to an open space near the Physical Sciences Library at the University of Canterbury. This experimental building had served its purpose and completed the first life cycle as a test specimen. Therefore it was now ready to be dissembled for recycling and reuse. Hence, this chapter will evaluate the deconstructability of the Pres-Lam system to provide an answer to the question: "How easily can the prefabricated components in the Pres-Lam system be disassembled and reused for reconstruction?"

9.2 Deconstruction Method

Mainzeal Construction Ltd. was engaged to deconstruct the experimental building at the UC Structures Laboratory. The objective of the deconstruction was to work with the building contractor on site to collect data and information from the deconstruction process of the experimental building. Time and cost of deconstruction were investigated. Lessons learned were documented for future Pres-Lam building projects.

Before the deconstruction work began, the main concern was whether the deconstruction would create damage to the suspended TCC floors in the experimental building. How the TCC floor units should be dismantled (cut out) so that floor diaphragm action could be formed again when reused later for reconstruction was a major concern. Review meetings were conducted between the client representatives (from UC and STIC), architects (from Thom Craig Architects), engineers (Holmes Consultancy Group), contractor (Mainzeal) and other parties involved:

- To discuss the structural perspective on how to effectively rebuild the building.
- To investigate and plan in detail the deconstruction and reconstruction.
- To come up with a set of measures to salvage the experimental building.
- To facilitate the reconstruction of the STIC office at a later stage.
- To determine the best approach for getting building consent.

The main intention was to avoid damage during the deconstruction process so that the whole building could be recycled and reused. A set of sketches show the method of deconstruction of the experimental building as produced by the engineers (Holmes Consulting Group-Mr. Richard Seville). For further details please see Appendix 11. Subsequently the deconstruction programme was produced by the author, and was reviewed and approved by Mainzeal for the planning, co-ordinating and monitoring during the deconstruction.

Once the deconstruction planning and other measures were in place the deconstruction work began. On 26th May 2010, the deconstruction of the 2 storey experimental building was started. The deconstruction sequences for the experimental building are represented graphically in Figure 48 and the deconstruction steps are described as follows:

- **Step 1**-The deconstruction sequence of the 2 storey building begins with mobilisation of labour, subcontractors, tools and equipment. All workers involved were informed on the requirements of health and safety issues. The deconstruction work of the building was planned to commence with dismantling of the suspended TCC floor units. These floors needed to be cut and removed as according to the original prefabricated floor sizes. Therefore the location lines for concrete cutting of the floor units at the 1st storey and 2nd storey of the building must be accurately marked right in between the middle of the double floor joists.
- **Step 2**-Prior to the commencement of the concrete cutting on the suspended TCC floors, these floor units needed to be temporarily supported from the bottom. The four corners of the columns were also securely braced and propped.

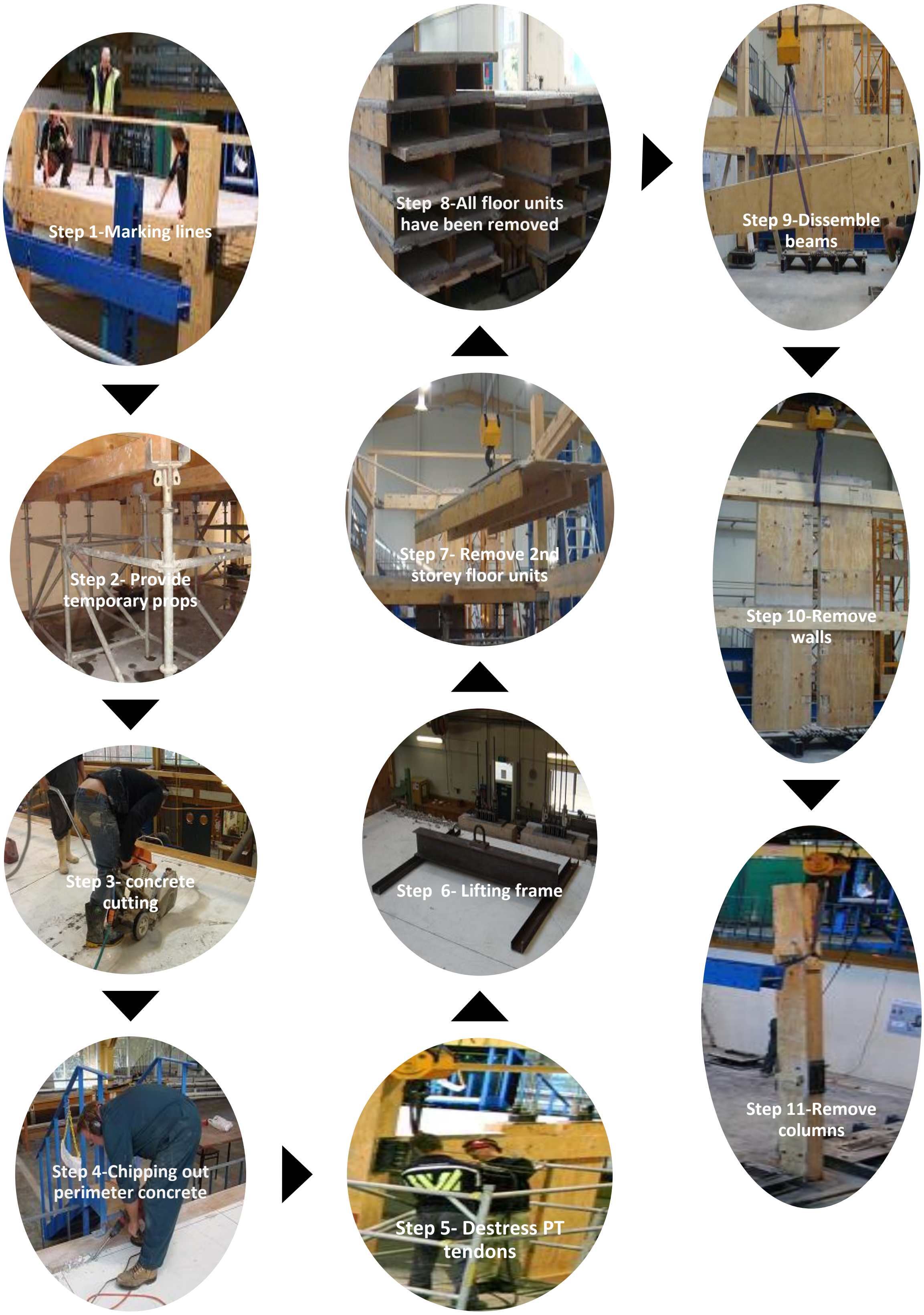


Figure 48: The Deconstruction Sequence of the 2/3 scale Experimental Building.

- **Step 3**-For speed and manoeuvrability, a semi-automatic concrete cutting machine with wheels, and a hand held concrete cutting tool were used to cut the concrete topping on the suspended floor units. The thickness of the concrete topping was 50mm. It should be note that only 40mm of the concrete topping was saw cut. This was to ensure that the plywood and the LVL floor joists would not be cut or damaged. Concrete cutting commenced on the first storey and followed by concrete cutting on the second floor. Temporary props to support the second storey floor units were provided prior to the concrete cutting work.
- **Step 4** -Once the concrete cutting had been completed, the screws connecting the LVL floor joists were removed. The perimeter concrete on top of the beams at the second storey was chipped out around the end of the floor joists so that splits between the floor units could be located and the crushed concrete debris removed. U-shaped reinforcing steel hooks that form the floor diaphragm were cut off and all the wood screws connected to the plywood, and screws connected to the top steel plate hangers for the floor joists were removed.
- **Step 5**-At this stage the distressing works of the post–tensioning tendons at first and second storey beams began. Subsequently the post–tensioning tendons for the walls were distressed. All the temporarily bracing to resist lateral movement still remained. Once the distressing had been completed, the tendons were cut and removed from beams and the walls.
- **Step 6**-A specifically designed and fabricated lifting steel frame (spreader beam) was used to lift out the TCC floor units. Four holes for 4 × Ø 20 mm steel bolts at four ends of steel channels were used as lifting bolts. The steel frame was placed on top of the floor unit at the centre so that the location of the holes could be marked. Drilling on top of the concrete topping was done with a hand-held drill. Once all the fixing (4 × Ø 20 mm) bolts with washers were fastened and fixed on the lifting frame, the floor units at the second storey were lifted out. In order to lift out the floor units without any hindrance, it was ensured that all the wood screws attached to the plywood, and the 50mm concrete topping were completely cut through.
- **Step 7-** The process to lift out the floor units was relatively simple. The TCC floor units each weighs about 1 tonne and were lifted out using the available 7.5 tonnes capacity gantry crane. Once all five floor units from the second storey had been removed, the temporary props used to support the second storey floor units were

dismantled and removed. The set of walls and edge beams at the west side of the building were then disassembled.

- **Step 8-** At this stage the perimeter concrete on top of the beams was chipped out at the first storey, and all the works in Step 4 were repeated. Once all the miscellaneous work had been completed, the suspended floor units from the first storey were lifted out. There were six floor units on the first storey. Once all the TCC floor units were removed, temporary props used to support the first storey floor units were dismantled and removed.
- **Step 9-** From here on, the disassembly of the structural frame was initiated. The process to dissemble the beams was relatively simple. Each beam only weighs about 0.22 tonnes and was secured to the hook of the crane with a lifting strap. Prior to the disassembly of the beams, all the columns remained temporarily braced and propped. All the beams were attached at each end to the corbels with two wood screws during construction. Before each of the beams was removed, these wood screws were removed. First the beams at the second storey were removed, followed by the first storey floor beams.
- **Step 10-** The remaining set of walls and edge beams at the east side of the building were removed and taken apart to ease storage.
- **Step 11-** Before the columns were removed from the steel foundations, the energy dissipation steel rods ($4 \times Ø$ 25mm) at the base of the column were unfastened. Finally all the six columns, each weighing about 0.25 tonnes, were taken down.

9.2.1 Deconstruction Time

The deconstruction process was successfully completed with no cracks and no major damage that could be seen on the TCC floor units when the floor panels were dismantled. The deconstruction process only utilised an average of two labourers, and a 7.5 tonnes gantry crane to disassemble the experimental building in six days utilised the total of 122 man hours using 2 workers. The detailed breakdown of the deconstruction work in man hours can found in Table 8.1. The actual time taken to deconstruct the building was found to be the same as the initial planned deconstruction programme (refer Appendix 13).

Table 17: Breakdown of the deconstruction work

		Labour in Man hours
1	Mobilisation & enabling works	6
2	Marking of lines for concrete cutting	4
3	Temporary supports (setting up and dismantling)	16
4	Concrete cutting	12
5	Distressing and removing tendons	14
6	Chipping out perimeter concrete, remove screws and other miscellaneous works	24
7	Dismantle the floor units	18
8	Dismantle the beams, columns and walls	16
9	Others	12
	Total time used	122 (man hours)

The percentages of time used for each activity in the deconstruction process are illustrated in a pie chart in Figure 49. The main components in the building consisted of the TCC suspended floor units, beams, columns and walls and were dismantled with only two workers and utilised only 27 % of the actual time. That means about 73% of the time was spent on preparation works prior to the actual deconstruction of the structural components.

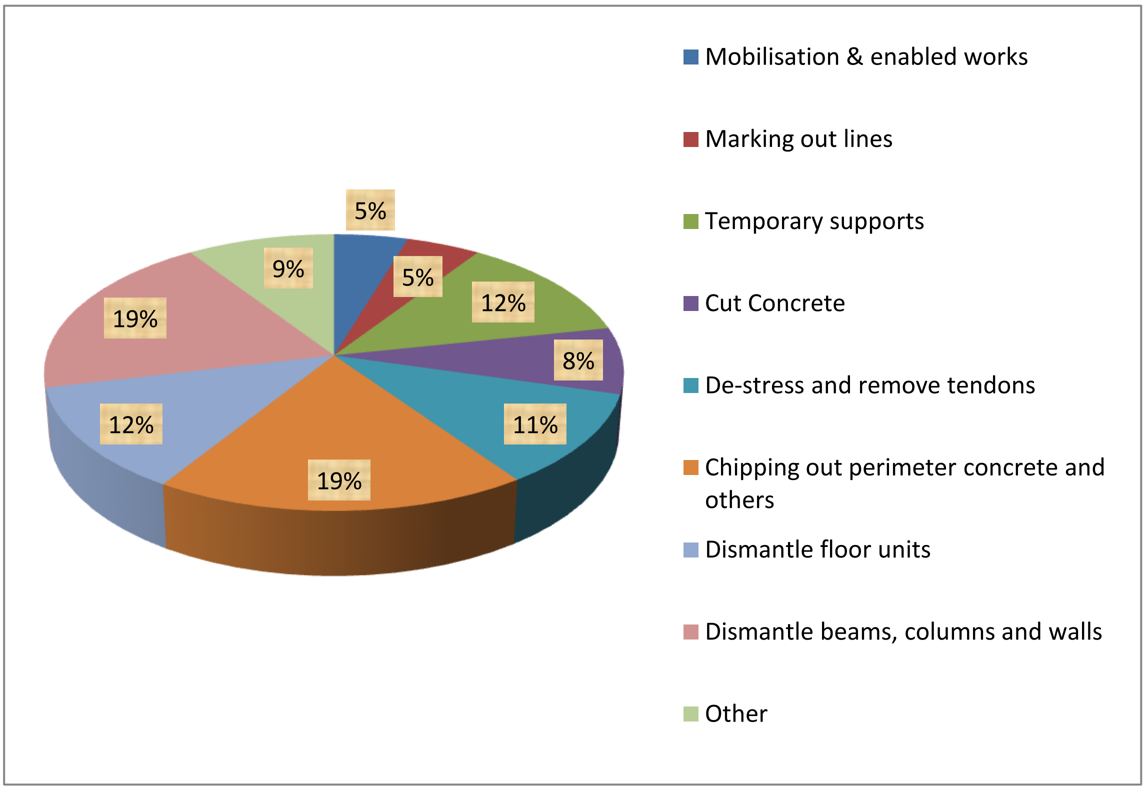


Figure 49: Man hours used in deconstruction

9.2.2 Deconstruction Costs

The percentage of time spent on each activity is directly related to the deconstruction cost. The followings items (crane for lifting; scaffolding for temporary supports; hydraulic jack used for distressing; electronic drill and breaker, tools and equipments used for drilling and chipping out concrete) were all available in the UC Structures Laboratory, therefore were provided free of charge. However to work out the deconstruction cost, the current market rates were used for the estimate. The cost information came from quotations received from Mainzeal contractors (Mr. Paul Blackler) for the concrete cutting and reference to Giddens (2009) Rawlinson's handbook. The aim of the deconstruction cost analysis was to identify the unit rate per square metre of the Pres-Lam system.

The total deconstruction cost of the experimental building was expected to be $10,420 and labour contributed 42% or $4,360 to the deconstruction cost. The costs for tools, equipment and crane hire contributed 58% or $6,060. This provided a cost ratio of 40:60 for the deconstruction of the Pres-Lam system. The deconstruction cost was further analysed as shown in Figure 50, divided into mobilisation and enabling works; temporary bracing and propping; concrete cutting; de-stressing and removing tendons; chipping out concrete and miscellaneous work; labour to dissemble the structure; and the crane. Market estimated crane hire costs contributed 25% to the total deconstruction cost. Labour to dismantle the suspended floor units, beams, columns and walls contributed only 19% of the total deconstruction cost. Concrete cutting was done by Mainzeal using market rates at a lump sum of $1000. Labour to destress and remove tendons, and chip out concrete and miscellaneous works was the most time and labour intensive portion, which contributed 29% of the deconstruction cost.

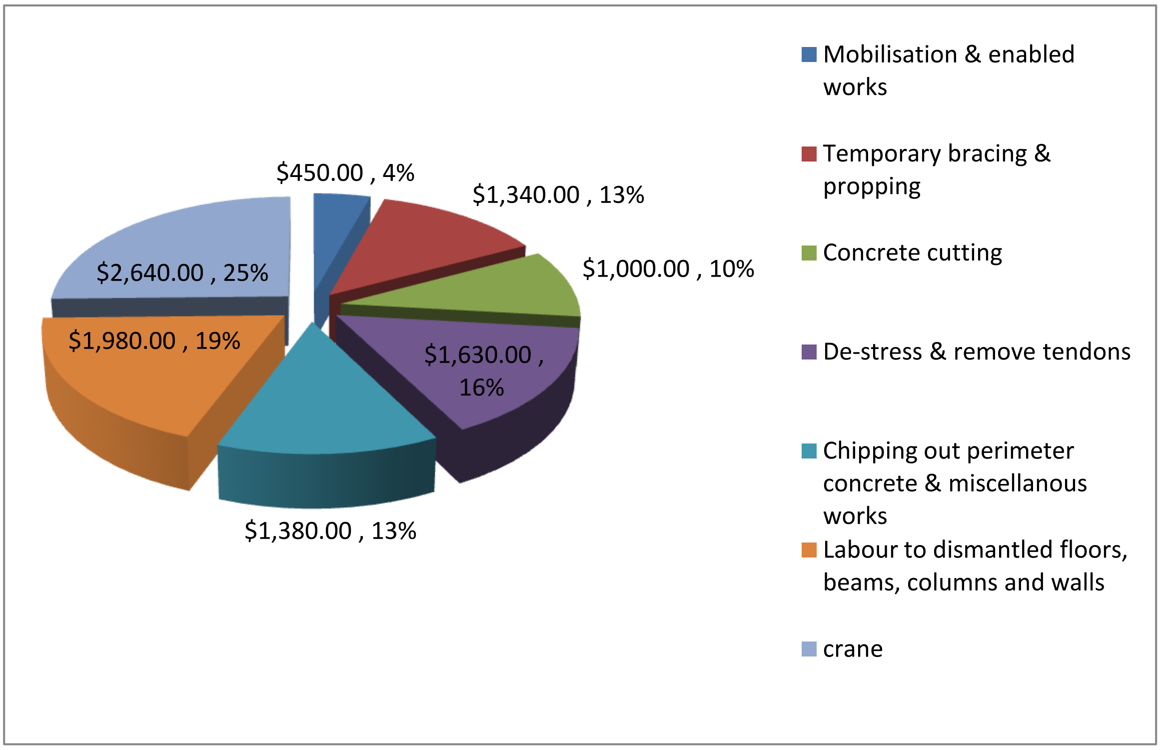


Figure 50: Deconstruction costs and percentages of the total cost

The breakdown of the cost analysis spreadsheet can be found in Appendix 12. The deconstruction cost in unit rate per square metres for the Pres-Lam system has been identified as $125 per m². This is a cost effective competitive price for deconstruction of a building where 95% of the materials can be reused and the process was labour intensive and required careful and skilful construction techniques. Compared to a reinforced concrete floor slab, concrete wall and metal roof two storey office building, the demolition cost was expected to be in the range from $65/m² to $ 100/m². Demolition of a concrete building was less labour intensive and it is expected that only 30% of the materials can be recycled or reused. Concrete floors and walls are normally crushed into border or concrete debris for backfilling. Reinforcement steel is sold as scrap metal, roof truss and metal roofing sheets can be recycled and reused.

9.2.3 De-constructability

The deconstruction process was completed in 6 days (122 man-hours) and at an expected cost of $10,420 using two workers. Deconstructing the experimental building was fast, flexible and simple. However, the time for the deconstruction process was expected to be faster if the process was done by Manizeal contractors. Mainzeal was originally contracted for the deconstruction of this building but was only able to be involved at the beginning of the deconstruction (1.5 days) because of their other commitments. The majority of the deconstruction work was completed by the UC structural laboratory technician (Mr. Russel McConchie and the author). The light weight structural components simplified the manoeuvrability of the components, and the simplicity of the connection details and the unbonded PT tendons contributed to the overall efficiency of the deconstruction process for the Pres-lam system. In addition, no health and safety issues arose and the deconstruction process was completed with zero accidents.

Following this deconstruction of the experimental building, 95% of the structural components for this building were able to be salvaged for the reconstruction of the STIC office building. Only 5% of building waste has been sent to the landfill. The limited waste generated consisted of mainly concrete debris come from the concrete cutting, remaining steel reinforcement, and used post-tensioning tendons.

A time lapse deconstruction video for this building has been produced. To view this video refer to Appendix 13 for a link to the video.

9.3 Lessons learned from Deconstruction

The completed deconstruction process of the experimental building has generated valuable data from which lessons can be learned. This can be utilised for any future Pres-Lam buildings. The following are the lessons learned:

- During deconstruction when lifting out the floor units, some of the units had problems because the concrete topping and steel reinforcement were not fully cut through. Concrete cutting should be 50mm deep (the full thickness of the concrete topping) instead of 40mm so that the concrete topping was fully cut.
- Self drilling Tek (Type 17-14 gauge) screws which have a protruding head should be used instead of countersunk square drive wood screws in order to be easily spotted and easily removed.

- An efficient floor connection system should be used (see Section 5.3.1, Figure 26a) to achieve floor diaphragm action at the edge of the pre-cast slab, using counter sunk screw holes cast in to the concrete topping at the casting yard is recommended. This floor connection will ease the construction and deconstruction of the floor units.
- Concrete filled notches on the plywood and on the LVL floor joists should be avoided to prevent concrete spalling during lifting if it is not cut right through during deconstruction.
- Perimeter floor joist supports or long corbels (as according to the second Storey floor design) should be used to ease the deconstruction as well as construction. However, screws should be fastened in a way that they won't be blocked by floor joists to ensure easy removal. This also eliminates the need for concrete cutting and chipping out perimeter concrete, improving the efficiency of disassembling the TCC floor units.
- In some of the floor units, the plywood was found to be delaminated from the concrete topping. Although the plywood only served as permanent formwork with no design load bearing capacity, it was visually unacceptable.

9.4 Remedial Works for the Experimental Building

To transform the experimental building into a new STIC office building, most components of the existing experimental building would be fully utilised. The head room for the second level will be increased to 800mm by moving the upper level beams so that the tops of the beams are at the same level as the tops of the columns. Therefore some minor modifications to the deconstructed building components are necessary (See Appendix 14). All the remedial works were done at the UC structural laboratory. The structural design and the remediation works design of the new building were done by Mr. Richard Seville from the Holmes Consultancy Group with assistance from PhD candidate Michael Newcombe. The following are the remedial works required to be carried out:

1. The walls will be extended due to forces in the diaphragm at the first floor where the stair void has been cut out. The height to be extended (800mm) is to match the height of the columns but this measurement is to be confirmed on-site. The wall extensions are to be connected with four grade 8.8 Ø20 threaded bars. The bars are to be 700mm long with 350mm embedment and spaced 50mm apart with 75mm edge distances. Pre-drilled (Ø 25 mm) holes at top and bottom of the walls would accommodate the epoxied rods.

2. One column was cracked from the testing which required part of the column to be replaced from the bottom of the top corbel to the top of the column. The replacement length of the new column segment was about 1380mm. The connection for the new column is similar to the wall connections, four grade 8.8 Ø20 threaded bars of 700mm long with 350mm embedment would be used. The bars are to have 75mm edge distances across the grain and 100mm along the grain, with pre-drilled (Ø 25 mm) holes at the top and bottom of the columns to accommodate the epoxied rods.
3. The beams were relocated to be flush with the tops of the columns. New holes needed to be created in all columns to accommodate the post tensioning (MacAlloy 1030 bars) that pass through the columns.
4. At the base of all the columns, four predrilled holes are required for the specially prefabricated 25 mm thick base connection plate that come with 4 M30 treaded bars expoxied into the timber columns.
5. Due to changes in design in the way the floor system is connected to the structural frames, 34 sets of specially designed double floor joists steel hangers are prefabricated for the future reconstruction of the TCC floor units.
6. One of the TCC floor panels in the first storey needed to be cut into half to accommodate the future spiral staircase.
7. The remaining existing concrete debris at the top of all of the LVL beams needs to be removed.

9.5 Summary for Deconstruction

Deconstruction is a trend towards sustainable building construction. From the deconstruction of this experimental building, the Pres-Lam system is shown to be a truly sustainable building material as 95% of the structural components for this building have been able to be salvaged for recycle or reuse. However, due to a spiral staircase added to the STIC office building only 90 % could be reused. Only 10% of the material has become building waste, which can be sent to the landfills be recycled or used as backfill material. This is significantly less than typically constructed buildings.

The constructability and the deconstructability of the Pres-Lam system can be further improved from the lessons learned. If the original design of this experimental building anticipated that the building would be deconstructed for recycling and reuse, then during the earliest stages of the original design and planning, connection details should be incorporated that improved the overall constructability and deconstructability of the Pres-Lam building.

Therefore it is essential to include deconstruction as part of the overall project. However in reality this is not common practice, but should be considered for future designs.

Chapter 10: Case Study (2) Reconstruction of STIC New Office Building

10.1 Background

After the completion of the remedial works of the dissembled components for the experimental building, the reconstruction of the STIC building will be carried out by the general contractor Mainzeal Construction Ltd. Architectural design of the new STIC building was designed by Thom Craig Architects Ltd. and the engineering was designed by Holmes Consulting Group, Christchurch.

In this part of the research, the author will act as a "project manager" (PM) representing the contractor in the pre-construction stage, assuming that the contract was awarded based on selection from the qualification and experience of the contractor. This aims to cover the construction management project planning and to identify the projected construction time and estimated cost for the proposed reconstruction of the STIC office building at the University of Canterbury based on the project manager roles and responsibilities.

It is the main priority of a project manager to meet the objectives of the client and to fulfil the project goals. The aim of the project is to ensure that it is completed on time within the budget, without compromising quality and while satisfying the specification requirements. Therefore a master reconstruction programme will be produced for project planning and control. Subsequently, projected reconstruction costs estimating will be produced for the later construction which the project manager will use for construction budget monitoring and control. The potential reconstruction problems of the system will need to be identified and the potential solutions will be discussed with the contractor before the commencement of work.

10.2 Reconstruction Project Planning

Project planning is intended to avoid project time and budget cost overruns. In order to manage a project from start to finish, it is essential to understand the project scope. A PM must know exactly which tasks are to be completed, when they need to be completed by and how to accomplish them according to the specification. It is important that a PM is able to determine the available resources, to check the timeline, to assemble a project team, to identify project goals and to ensure the successful completion of the project. A PM is also needed to develop the master reconstruction programme and to identify any potential problems that might arise during reconstruction and to provide solution to the problem.

10.2.1 Project milestones and deliverables

Identifying the project milestones and deliverables is the key to achieving the project goals. Milestones show the important date of a project, usually based on the completion of a major deliverable. The development of a project normally consists of various phases needing to be managed effectively. As for the STIC project, the reconstruction will be managed in two phases; the actual construction time is estimated to take 14 weeks, while the commissioning and handover of the project is estimated to take approximately one week. The total development for reconstruction of STIC was estimated to be approximately 15 weeks. Table 18 shows the project management milestones and deliverables.

Table 18: Project milestones and deliverables

Phase	**Milestones and deliverables**	**Estimate date**	**Estimate Duration**
Phase 1	Construction phase	15th September 2010 to 20th Nov 2010	14 weeks
Phase 2	Commissioning and Handover	20th Nov 2010 -23rd Dec 2010.	4 days (approximately 1week)

Once the project milestones and deliverables have been identified, the PM needs to identify the key activities in order to establish the estimated budget; the start date and the estimated duration to complete the each activity (see Table 19). The project is planned to start tentatively on 15th September 2010 and the handover to the STIC 23rd December 2010. This information is essential to the project manager in order to manage and to control a project effectively.

Table 19: Key activities, estimated budgets, start date and estimated duration.

Key activities	Estimate budgets	Start date	Estimate Duration
Mobilisation & Enabling works	$10,000	15th Sep 2010	1 week
Substructure	$32,000	23rd Sep 2010	6 weeks
Structure work	$81,000	5th Nov 2010	1.5 weeks
Roof & Building Envelope	$61,000	11th Nov 2010	3 weeks
Internal works	$52,000	16th Nov 2010	3 weeks
External works	$5,000	13th Dec 2010	1 week
Prepare for Handover	$19,000	20th Dec 2010	1 week
Total Estimated Reconstruction Costs	**$260,000**		**15 weeks**

10.3 Reconstruction Methodology

The methodology used for the reconstruction of the STIC building is expected to be similar to the previously assembled experimental building before it was deconstructed. Previously the experimental building was erected by Mainzeal with an average of 15 hours (approximately two working days) and required four workers (Newcombe, 2010). However, this time, the reconstruction method would be more challenging as it is an actual office building that: foundation, footings with timber piles for wooden ground floor, cladding, roofing and all other common features that can be found in office buildings. The challenges are as follows:

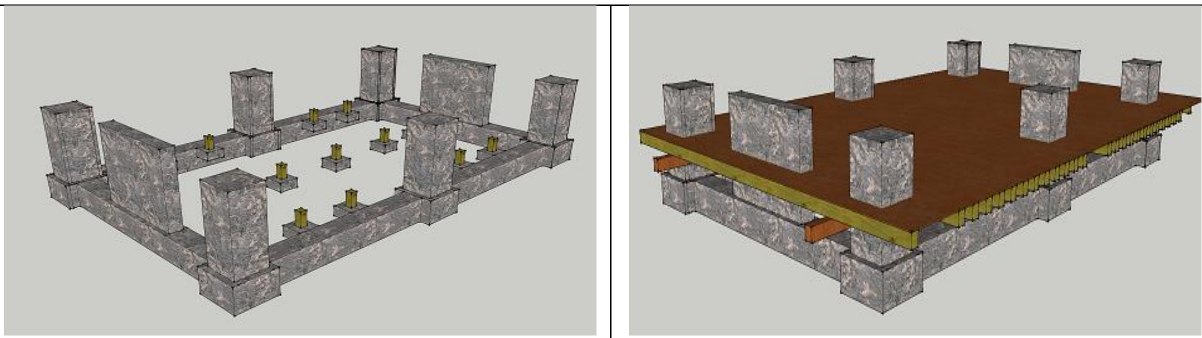
- The original columns and walls heights are not standard because it was previously used as an experimental building. Therefore, the columns and walls are supported on concrete plinths of 1000 mm high to achieve the required floor to ceiling heights.
- There are four strip foundation beams (500 mm x 400 mm) that run the perimeter of the building, and 800 mm square pads under each of the columns. Inside the building, there are 13 concrete footings (400 mm) square used to support the wooden ground floor.
- The construction sequence of the foundation beams begin with the excavation of the trenches; hard fill is placed and compacted, formwork placed, reinforcement placed and fixed, and the foundation beams are poured.
- The formwork is stripped in the following days, and the foundation is backfilled and compacted to its existing ground level.
- The next step is to place and fix reinforcement for the columns and wall plinths and to construct the small footings, once the formwork for the plinths and the small footings

are placed (see Figure 50a); insert hold down bolts (anchorage) for the steel shoes for columns and walls; and the columns; wall plinths and the small footings are poured; backfilled and compacted to the ground level.

- The wooden ground floor will be constructed to the required floor level as shown in Figure 50 (b). The wooden ground floor is supported on joists bearers (190 mm x 45 mm) and 125 mm square timber piles. The wooden ground floor will serve as an immediate working platform for the erection of the structural components.

The preparation works for the erection of the prefabrication Pres-Lam can then begin. Prior to the erection of the Pres-Lam structural members, it must be ensure that the protruding hold down bolts on the columns and wall plinths are clean and levelled, ready to receive the Pres-Lam prefabricated components. Before the structural LVL is delivered to site for storage or erection, it will be protected (wrap in plastic or otherwise) from exposure to rain and damage during transit.

The reconstruction sequence for the STIC 2 storey Pres-Lam building is represented graphically from Figure 51 up to Figure 54.



a) b)

Figure 51: (a) Strip Foundation Beams, Column plinths, Wall Plinths and small footings and (b) Erect Wooden Ground floor

The reconstruction sequence for the STIC 2 storey Pres-Lam building is outlined in the following steps:

- **Step 1-**The assembly sequence will be from the east direction to west. Workers will lift up the LVL column which is on average about 7.5metres high. The column is then moved into position and placed at the corner of the building (see Figure 52a). At the steel base of the column the hold down bolts are fastened (Figure 53). The column will be vertically plumb and temporary bracing will need to be introduced as this will serve as the guide for the remaining erection works. This bracing can only be removed when the building is very stable.

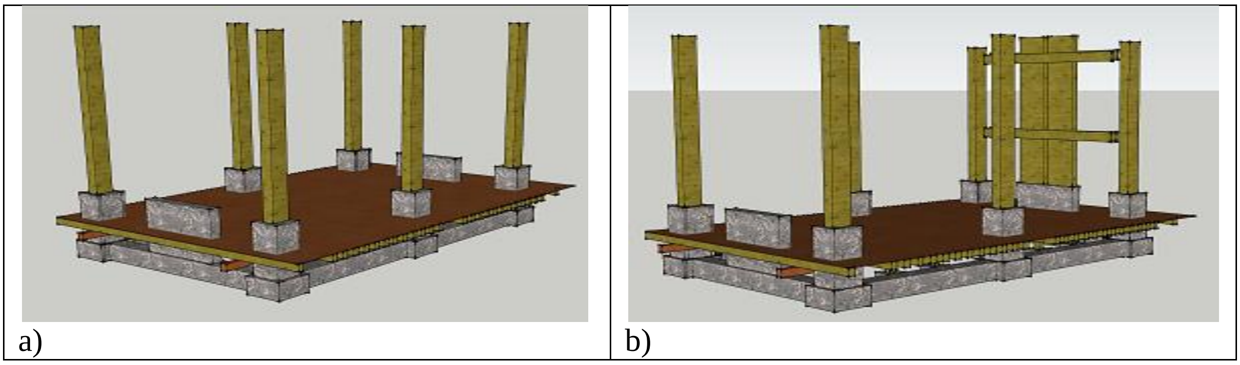


Figure 52: (a) Erect Columns (full height) and (b) Install east side end frame (walls and edge beams)

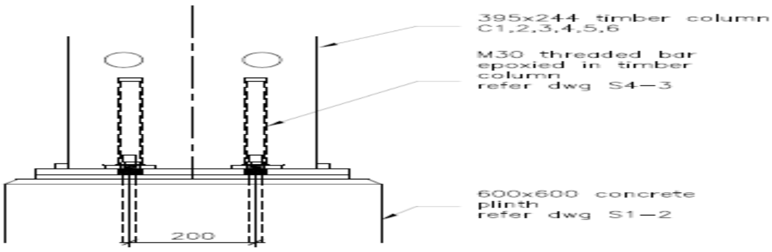


Figure 53: Details for column base connection (courtesy of Holmes Consultancy Group)

- **Step 2-** At the ground level, the walls and the edge beams are assembled together as a frame to ease erection. MacAlloy 1030 bars are placed in the cavities from the top of the walls, and are fastened to a thick bearing plate with nuts. Workers will lift up the frame (walls and edge beams) into place with a crane to the building (Figure 52b). The MacAlloy bars are connected together to the cast-in MacAlloy bars in the wall plinths with couplers at the base of the walls. The walls are then fastened and securely braced.
- **Step 3-** Prior to the installation of the beams, fabricated steel inserts must be placed at all column-beam joints on Level 2. The beams at Level 2 are then placed on the steel corbels provided. The beams are held in position with temporary fasteners. It is recommended by the engineer to remove these fasteners after the beams are stressed. Repeat this step for the beams at roof level (see Figure 54a).

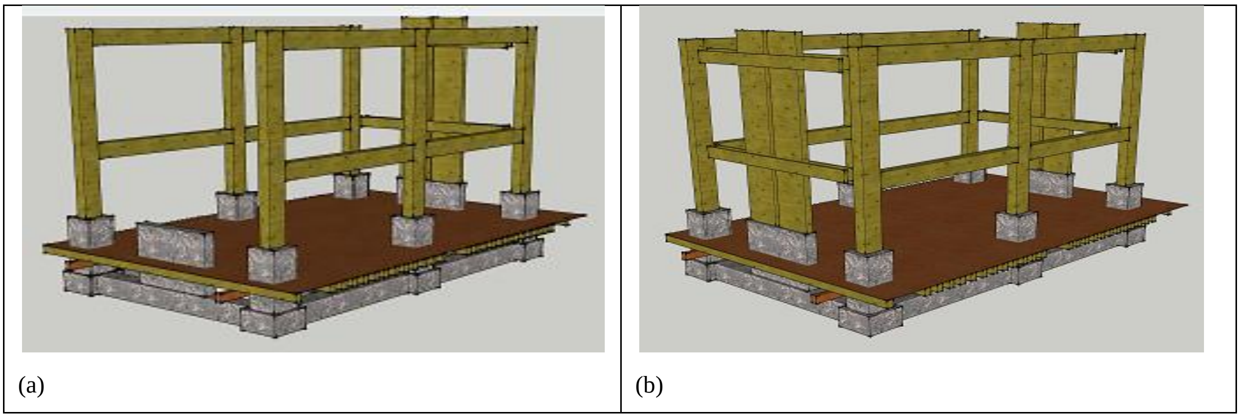


Figure 54: (a) Install beams (b) Install the east and west of the end frames

- **Step 4-** Subsequently the MacAlloy bars are placed into the cavities of all the beams and securely fastened. Specially prefabricated steel floor joist hangers must be bolted to the beams, ready to receive the TCC floor units (see Figure 55). The next step is to install the TCC floor units (Figure 56a). The same lifting spreader beam that was used to deconstruct the floor units will be reused to install the TCC floor units. The floor units are supported by edge beams attached to LVL walls at the ends of the building and a primary beam in the middle of the building.
- **Step 5**- Temporary supports for the TCC are required. Once all the temporary supports are in place, then the TCC floor units are placed. The floor units must be fastened to the frame and edge beams. Repeat this step for the TCC floor units at the roof level except that at the roof level floor joists are oriented at 90 to those at Level 2 and are supported by frame beams with attached LVL corbels.

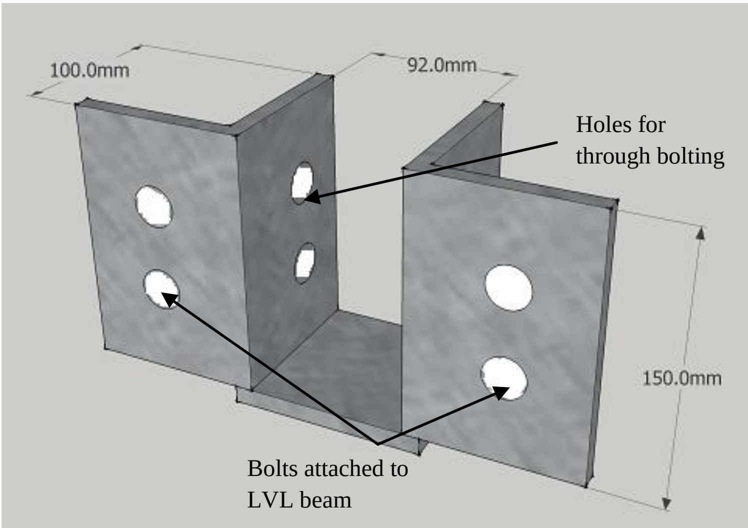
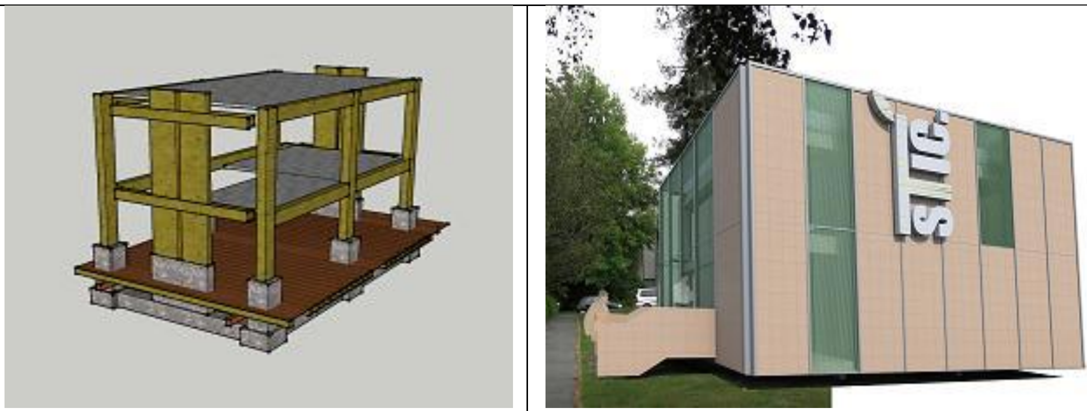


Figure 55: Proposed Prefabricated floor joist hanger

- **Step 6-** The TCC floors are connected together to beams with in-situ concrete joints. The formworks for the perimeter slabs for both levels are placed. Once this is done, the steel reinforcements and wire mesh are placed and fixed, and subsequently the perimeter concrete joints are poured.



(a) (b)

Figure 56: (a) TCC floor are placed (b) Architectural Impression of the completed STIC building-(Courtesy from STIC Ltd. and Thom Craig Architects)

Once the structural works for the building are completed, all architectural fit outs, mechanical, electrical, plumbing and other services work continue to progress as planned. The cladding of the external building will use a combination of “ECOPLY” prefabricated panels and “PSP© PLEXIGLAS”, a type of clear acrylic glazing system for sunlight, used to showcase the aesthetic beauty of the Pres-Lam structure. The architectural impression of the completed STIC building is shown in Figure 56b. For detailed drawings of the building, please refer to architectural and engineering drawings in Appendix 16.

Alternatively, the STIC building can be constructed by assembling the frames (along Grid Lines A and C) in a segmental form, horizontally on the ground. The frames were then post-tensioned (PT) and tilted upright into position. Using this construction method, it is expected to reduce the construction time because PT works can be carried out on ground level.

10.4 Reconstruction programme

In order to develop an effective master programme and a budget for reconstruction planning, a good understand of the structure for the database (detailed tasks) is needed so that the information can be organised. Some assumptions also had to be made in order to predict the necessary time needed, these assumptions are listed below:

- For substructure works, allow two labourers in each trade; steel reinforcement fixing, installing formwork and to pour concrete.

- Man power during erection of the LVL system: two labourers, one supervisor and one crane operator.
- Assume that a 20 tonne mobile (truck mounted) crane will be used, with a lifting capacity of one tonne at the maximum boom length of 25 m. This is because the actual available parking location for the mobile crane is about 10 m away from the proposed building.
- Walls and edge beams at Grid Lines (A) and (C) will take one hour each to assemble into a frame on-site and take 30 minutes to an hour to place.
- Column members will take 30 minutes to erect, plumb and prop after arrival on-site
- LVL beams will take 15 minutes to place.
- TCC flooring units will take 20 minutes to place.
- MacAlloy 1030 bars will be placed once the beams are installed. Allow one day to complete the task. Post tensioning works are estimated to take two hours per anchor.

The estimated time taken for the construction and the elemental weight of the LVL of the structural building are tabulated as shown in Table 20.

Table 20: Estimated time taken for the construction and the LVL element weights of the structural building

Component	Unit (No)	Time (hrs/no)	Total Time (hrs)	Weight (tonne)
Excavation	1	1	8.0	-
Foundation beams	4	6	24	-
Footings	14	2	28	-
Columns & Walls Plinths	8	4	32	-
LVL column	6	0.25	1.5	0.35
LVL Frame (walls and edge beams)	2	0.5	1.0	1.03
LVL Beams	9	0.25	2.25	0.22
TCC floor	10	0.25	2.5	0.80

Based on the above estimated time taken for the construction of the structural building, the construction programme for the STIC building was produced as shown in Figure 57. This summary construction programme only shows the important milestones of the project. For a detailed construction programme (Gantt chart), please refer to Appendix 18.

To ensure a high quality standard of work to be achieved for the research, it is necessary to seek advice from a professional project manager (PM) in the construction industry to review the reconstruction programme. Mr. Paul Blackler from Mainzeal Construction Ltd. was chosen to review the construction programmes because of his knowledge from previous involvement in the Newcombe (2010) research. They are also the selected general contractor for the reconstruction STIC building project. The comment from the general manager Mr. Blackler is that he agreed with the planning in the reconstruction construction programme. He commented that the reconstruction programme showed that the estimated overall construction time of the building is 72 working days (15 weeks), when the site made is available by STIC to the completion of handover. This estimated time is practical and achievable.

According to the construction programme in Figure 57, the substructure work is the most time consuming and is estimated to take about 31 days (6 weeks). To erect the structural system nine days have been allowed. Building envelope works (external cladding), which include the work at the roof top, are estimated to be 18 days. Subsequently, the internal works are expected to take 19 days, and five days have been allowed for the external and drainage works. This planned construction programme (Gantt chart) will be use by the PM to monitor the actual progress of the construction work.

ID	Task Name	Duration	Start	Finish
1	PROJECT DURATION	72 days	Wed 15/09/10	Thu 23/12/10
2	start	0 days	Wed 15/09/10	Wed 15/09/10
3	Handover to STIC	0 days	Thu 23/12/10	Thu 23/12/10
4	CONSTRUCTION	72 days	Wed 15/09/10	Thu 23/12/10
5	Site Made Available by STIC	0 days	Wed 15/09/10	Wed 15/09/10
6	Site establisment & Enabling work	6 days	Wed 15/09/10	Wed 22/09/10
11	Structure	40 days	Thu 23/09/10	Wed 17/11/10
12	Substructure	31 days	Thu 23/09/10	Thu 4/11/10
32	Structural Pres-Lam system	9 days	Fri 5/11/10	Wed 17/11/10
51	Building Envelope -external wall	18 days	Thu 11/11/10	Mon 6/12/10
64	Internal works	19 days	Tue 16/11/10	Fri 10/12/10
93	External works	5 days	Mon 13/12/10	Fri 17/12/10
96	Prepare for Handover	4 days	Mon 20/12/10	Thu 23/12/10

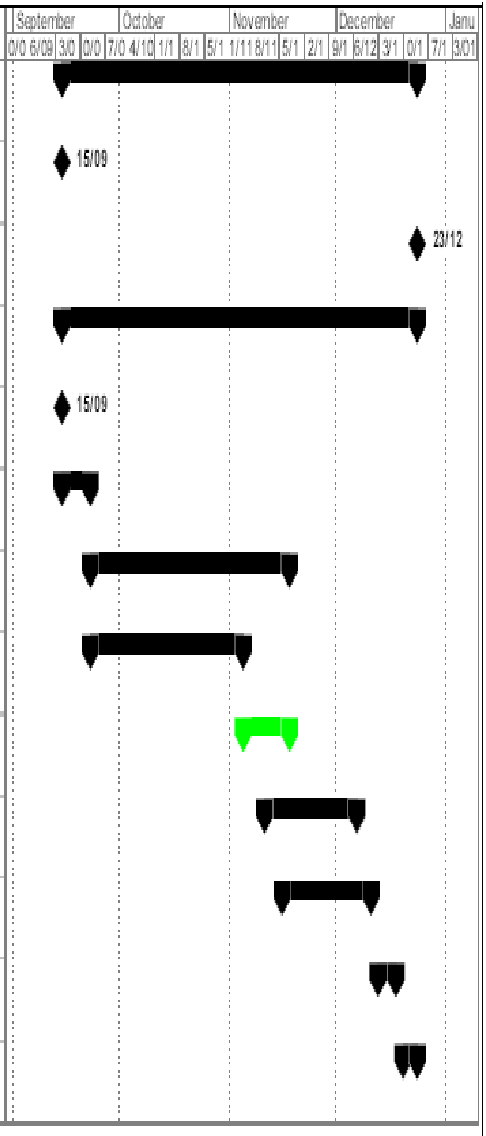


Figure 57: Construction programme for reconstruction of STIC building

10.5 Reconstruction Cost Estimate

At the pre-construction stage of the estimating process, in order to come up with a price as realistic and competitive as possible the following factors needed to be considered: the project organisation or the project team, the construction method, and the construction equipment. Most of these factors have been considered and assumptions had been made prior to the preparation of the reconstruction programme in Section 10.4. The aim of this section is to identify the projected construction estimate cost for the proposed reconstruction of the STIC office building, based on the project manager roles and responsibilities. The cost information was from quotations received from PSP Ltd. (Miss Mel Jackson) for the PSP

Multiwall cladding system (see Appendix 19) and reference to Giddens (2009) Rawlinson's handbook.

The estimated total reconstruction cost of the new STIC office building was projected to be approximately $260,118 (see Figure 58) which was divided into sub sections. The substructure works contributed 15% ($31,351) to the reconstruction cost. It should be noted that the LVL components are all available from the deconstructed UC experimental building, therefore were provided free of charge in this case. However, in order to produce a complete reconstruction cost estimation, the LVL components was assumed to have a recycled value of 70% ($50,000) of the original total construction cost of ($70,139) experimental Pres-Lam building. Therefore, the LVL components are contributed 20% ($50,000) to the building. The cost for labour, crane and equipment supplied by the general contractor to erect the structural system, which contributed 8 % or ($20,552) to the STIC building. The post-tensioning (PT) works contributed 5 % ($10,300) to the building, where future periodic maintenance costs of the tendons was excluded.

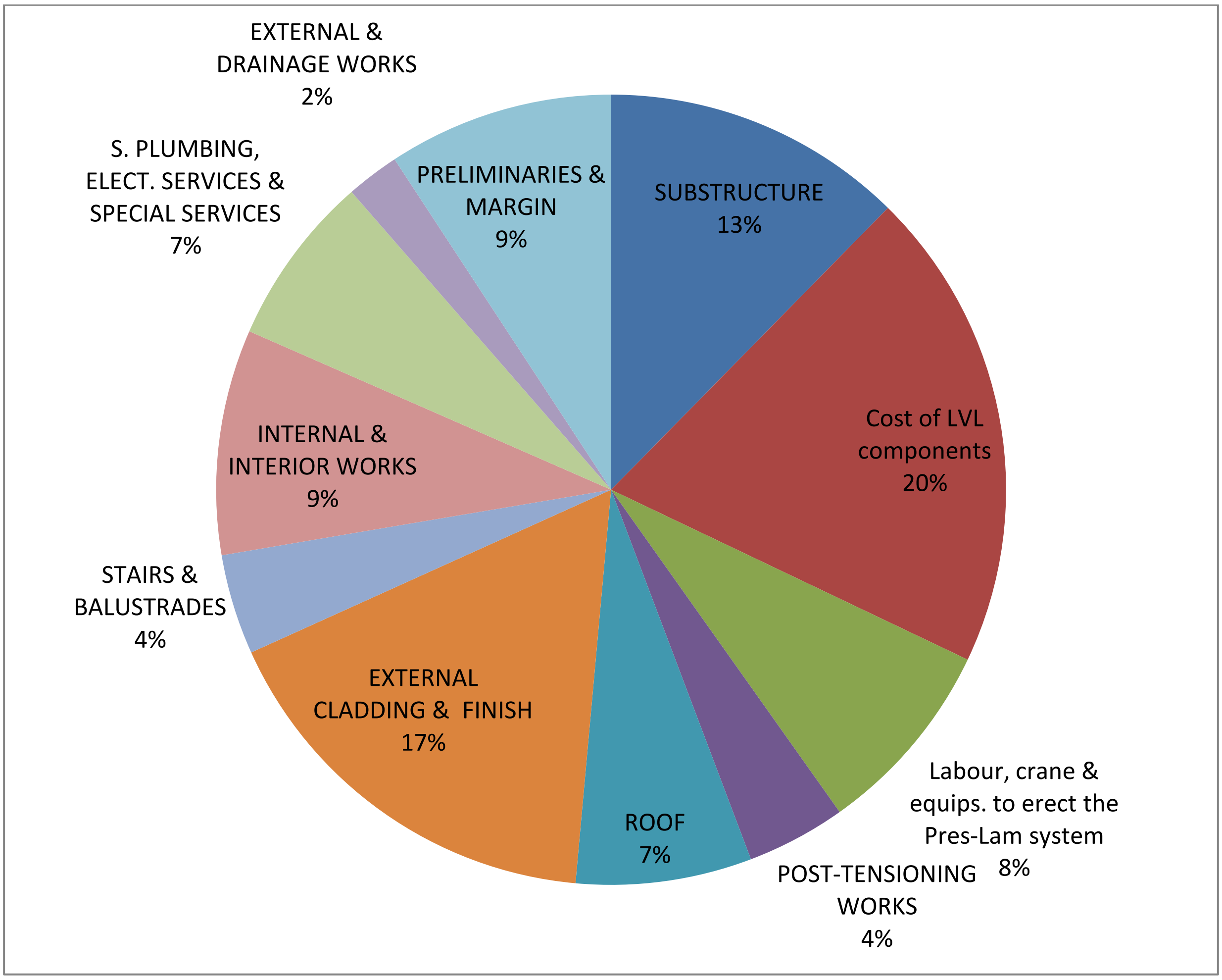


Figure 58: Estimated Reconstruction Cost for STIC building

All the works on the roof system, which are inclusive of the waterproofing, roof parapet walls and the clear acrylic in anodised aluminium PSP© glazing system contributed to 9% ($18,255) of the cost. The cladding of the external building will use a combination of "ECOPLY" prefabricated panels and "PSP© PLEXIGLAS"; a type of clear acrylic glazing system. This was the biggest contribution to the reconstruction cost at 21% ($42,624) of the reconstruction cost. The steel spiral staircase and balustrades contributed 5% ($10,400).The internal and interior works consisted of partition walls, ceiling and flooring contributed 11% ($23,390) to the building. Other services (sanitary plumbing, electrical and special services) contributed 9% ($17,800) to the reconstruction cost. The external works consisted of excess wooden ramp and drainage (sewer and storm water) contributed only 3% ($5,520) of the reconstruction cost. In this case the established building cost per square metre by using the Pres-Lam system for office buildings is identified to be approximately $ 2,060/m ^{2}
For a detailed construction cost estimate, please refer to Appendix 20.

The estimated reconstruction cost of the STIC building was reviewed by the senior quantity surveyor (QS) Miss Lorral Eder from Mainzeal Construction Ltd. She commented that it is essential to include all the elements in the reconstruction. Although the LVL components are were provided free of charge in this case, she suggested that if the intention of the research to promote the cost essentially of a new system then this should be factored in. According to Miss Eder "the budget estimate appears to be on the right side".

This estimated cost for reconstruction can be plotted into a projected S-Curve (see Figure 59). It will be used by the project manager (PM) during the construction phase for construction budget monitoring and control as the project progresses. The actual S-Curve will be plotted and compare it with the projected S-Curve to determine whether the project is completed within the projected time and budget allowed.

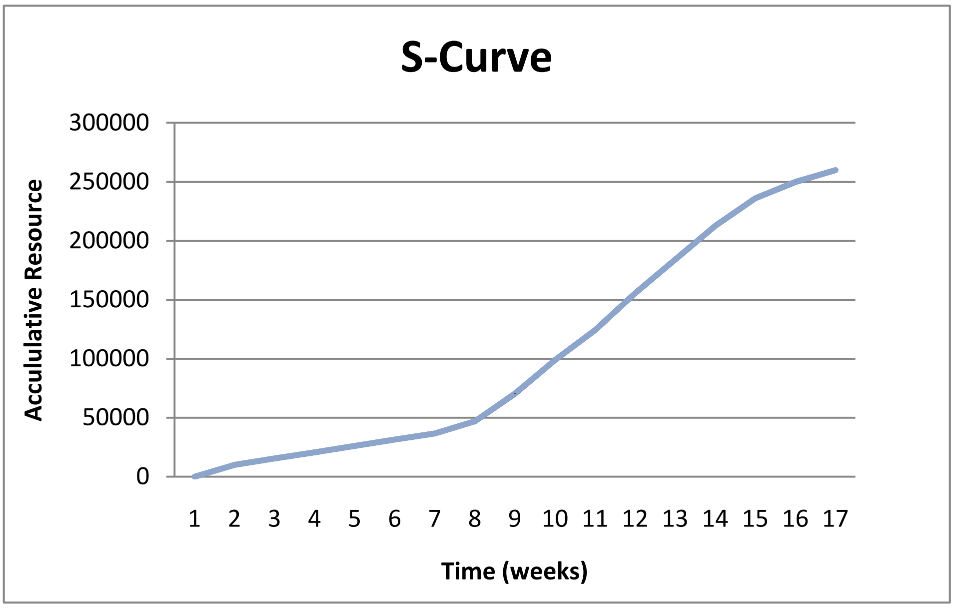


Figure 59: Accumulative Resource projected S-Curve

10.6 Summary

A master reconstruction programme, the construction method and the projected estimated construction cost of the new STIC office building have been produced. The reconstruction time of the STIC office building has been predicted to be 15 weeks and the estimated cost for the reconstruction to be $260,118. The reconstruction programme and the reconstruction cost estimation was verified by practising professionals (Mainzeal Contractors Ltd.) as practical and achievable.

This planned construction programme (Gantt chart) will be used by the project manager to monitor the actual progress of the construction work. This Gantt chart is an effective method of communicating planning information. The S-Curve can be used for construction budget monitoring and control.

Chapter 11: Conclusions

The main objective of this research thesis was to investigate the construction time (structures) and cost (entire building) of three virtual buildings (Pres-Lam, concrete and steel) for Case Study (1). The outcome of this research was aimed towards the construction industry in order to encourage the industry to consider Pres-Lam system for future projects. As described in section 1.3, there are three important questions that the research aimed to provide answers to:

1. What is the construction <u>time</u> of Pres-Lam timber structures compared with concrete and steel?
2. What are the construction <u>costs</u> of Pres-Lam timber structures compared with concrete and steel?
3. How efficient is the two storey STIC building at the University of Canterbury in terms of deconstruction and reconstruction?

This research managed to answer these questions through the optimisation and performance of the Pres-Lam system by collaborating with UC researchers, fabricators and contractors in the timber construction industry. The answers to the questions are provided in the following sections.

11.1 Conclusions from Case Study (1) Biological sciences buildings - Construction Time

In the construction time analysis only the construction time of the structural building portion was compared instead of the overall construction time of the building project. The research has been able to optimise the performance of the Pres-Lam system having increased open space with large column spacing than in previous designs. The proposed fully prefabricated double “T” TCC floor unit can reduce construction time. This means that all the LVL components in the Pres-Lam system can be fully prefabricated at a factory.

- The structural erection process of the Pres-Lam building would utilise a team consisting of four labourers to assemble the main structure, the predicted estimated construction time for the structural system is 60 working days (12 weeks).
- Compared to the simplified concrete structure construction programme which required 83 working days, the Pres-Lam system achieved an overall estimated time savings of 23 working days or about 4.6 weeks.

Hence, by using the Pres-Lam system the timber building is 38% more efficient than the concrete building in terms of structural construction time. The selection of a Pres-Lam system reduces time as it is a rapidly fabricated system and has a beneficial effect on other major variable cost items such as foundations, crane usage, transport, cladding and other services, leading to significant cost savings for the overall project.

11.2 Conclusions from Case Study (1) Biological sciences buildings - Construction Cost

The construction cost estimation for the concrete, steel and optimised Pres-Lam overall buildings including claddings and architectural fittings were produced and compared. The research has been able to identify the unit rate per cubic metre and unit rate per square metre of the Pres-Lam system. An interesting finding from this research is that by using a smaller capacity tower crane for the light weight of the Pres-Lam system, as compared with the concrete building, there is a cost saving of \$ 68,325 in crane usage which equates to 0.7 % of the total construction cost. The following established unit rates had been based on the current supplier LVL material cost of \$1400/m ^{3} and the fabrication cost of \$1000/m ^{3}. The current elemental construction costs in unit rates were investigated and a conclusion drawn as follows:

- The unit rate per cubic metre for the structural LVL frame fabricated into columns and beams was identified to be in the range of \$3,200-\$3,400/m ^{3}.
- The unit rate per cubic metre for structural LVL walls was identified to be in the range of \$3,700-\$3,900/m ^{3}.
- The unit rate per square metres for the fully prefabricated double "T' timber composite floor system was identified to be in the range of \$255-\$265/m ^{2}.
- The established building cost per square metre by using the Pres-Lam system for commercial and office buildings was identified to be approximately \$ 2,400/m ^{2} for a complete building.

Market price for the comparable concrete frames cost is around \$2,400/m ^{3} to \$ 2,500/m ^{3} and steel frames cost is \$5,500/tonne (Giddens, 2009). As the new structural system becomes more commonly used over time and the construction industry becomes more receptive to the structural system, the price of the Pres-Lam system is likely to come down in the near future.

Note: According to Mr Phil Schumacher from Davis Langdon Shipston Davis: “I have checked the LVL rates used, and they look to be very similar to those priced on NMIT Arts and Media Building”. Overall the results for the research in the Case Study (1) of the six storey Biological Sciences Building concluded that the construction cost of the Pres-Lam building has been estimated to be $ 335,124 (3.3%) more than the steel building and $ 468,395 (4.6 %) more than the concrete building. This minor difference of $\pm 5\%$ is often considered negligible in construction cost estimation. Furthermore the construction cost of a building is a relatively small part of the total cost of a project development. Therefore from the view of a prospective building owner, the benefits of early occupancy of their building and the ability to procure a building using the latest technology (in this case the Pres-Lam system) will outweigh small expenses in the initial stages.
Ultimately, there is potential for the reduction of the manufacture and fabrication costs of the LVL components as market maturation could close the gap. With the low cost of the LVL, incentives for the construction industry to change to this engineering building material will increase. It is expected that as the use of the Pres-Lam system is increased, the construction industry will be more receptive to the structural system and subsequently the associated risk will be reduced, leading to cost saving.

However the construction industry is conservative and many clients in this industry tend to choose a system based on the initial construction cost. Selection of a system to be used in construction should not be purely based on cost or on the lowest price bid in a project. Instead the construction industry should insist on best value selection where other parameters such as whole life cycle cost (LCC) and the environmental sustainability issues (life cycle embodied energy, CO_2 emission and CO_2 storage) of the building project are considered so that best practices in construction are applied.

11.3 Conclusions from Case Study (2) Deconstruction and Reconstruction of the Pres-Lam Building.

Case Study 2 investigated the deconstruction and reconstruction of the Pres-Lam building in terms of time and cost. The deconstruction for the Pres-Lam experimental building indicated that the deconstruction in terms of time and cost are as follows:

- Deconstruction of the experimental building (structure only) was completed in six days (122 man-hours) and the expected cost was $10,420 (equates to $125 /m ^{2}) using two workers. The deconstruction process was very efficient, flexible and simple. The main components in the Pres-Lam system were dismantled utilising only 27% of the deconstruction time. That means about 73% of the time was spent on preparation works prior to the actual deconstruction of the structural components.

- The deconstruction of this experimental building shows that the Pres-Lam system is a sustainable building material as 95% of the structural components for this building have been able to be salvaged for recycle or reuse. However, due to minor changes in new design of the STIC office building only 90 % will be reused. Only 10% of the material has become building waste, which can be sent to the landfills, recycled or used as backfill material.

Master reconstruction programmes have been produced, indicating the construction method and the projected estimated construction cost of the new STIC office building. The master reconstruction programme for the STIC building project is estimated to complete the project in 15 weeks utilised an average of four workers. The reconstruction cost (whole building) is estimated to be $260,118. In this case the established building cost per square metre by using the Pres-Lam system for office buildings is identified to be approximately $ 2,060/m^2.

11.4 Overall Conclusions

The research has been able to identify and established that the Pres-Lam system is construction time efficient and the construction cost is comparable to other alternative building materials. The simplicity of all the connections, the straightness and the lightness of the LVL prefabricated components, and easy manoeuvrability have increased overall constructability of the Pres-Lam structural system.

Based on the advantages that the Pres-Lam structural system offers, the future potential for Pres-Lam buildings is very bright. The world's first Pres-Lam building (NMIT) is already under construction (2010) in Nelson, New Zealand. This building paves the way for more multi-storey timber buildings to be built in New Zealand and around the world.

11.5 Recommendations

1. This research is unable to investigate the actual reconstruction of the STIC office building. Therefore further research is needed to investigate and to record the actual reconstruction time and cost.
2. Further research is needed to monitor more buildings in terms of the construction time and costs as they are designed and constructed.
3. Further research is needed to develop a more cost effective TCC floor system.

4. In order for the Pres-Lam structural system to be fully implemented and commercialised, it requires a culture change in the construction industry to move away from the traditional perception that timber is poor in fire resistance and acoustic performance.
5. Promoting the wider use of the Pres-Lam system in multi-storey building construction requires greater endorsement by clients throughout the construction industry in New Zealand and around the world, both in the private and public sectors.
6. In order to promote and disseminate the advantages of the Pres-Lam system for multi-storey building construction, the stakeholders of STIC Ltd should immediately arrange and organise technical promotional activities, including seminars, exhibitions and other related international expos for technical promotion.

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Appendices

Appendix 1: Case study (1) Structural Design for the Optimised Timber Building

The structural design calculation was performed by PhD researcher Michael Newcombe.

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Project:
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Seismic Design of Bio-sciences:

- 2 seismic bays
- L_{bay} = 8724mm
- Mass of floor ⇒ Not same as Toby's thesis.

W_i =	2321	– Roof –	1794	~ assumed
	2899	– L5 –	1794	5
	2899	– L4 –	1794	4
	2899	– L3 –	1794	3
	2970	– L2 –	1794	2
	3056	– L1 –	1794.	1
	(Old)		(New)	

- Toby was over-conservative in assuming the lateral load is taken only by the frames and assigning too much mass to the floor!

Dead G_i = 2.5 kPa
Q_6 = 3.0 kPa

- Importance level = 3 → Design life = 50 years.
- Return period = 1/1000 } NZS 1170.0
- Z = 0.22 (ch-ch)
- R = 1.3
- Soil = D } NZS 1170.5

⇒ $\xi_{eq} = \xi_{el} + \xi_{hyst}$ (Equivalent viscous damping)
= 6.2 %

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$\varepsilon_{elastic} = 5\%$

$\varepsilon_{hyst} = 1.2\%$

Design drift = 2.5%. $\{V_b = 1624$ kN$\}$

Resulting effective period = 2.13s.

$\Delta d = 0.336$m.

$M_b^* = 1229$ kN.m. – L1

⇒ hence : $\phi M_s \approx 2 \times 1229$

$= 2458$ kN.m

⇒ section size ≮ $Z > 60.7 \times 10^6$ mm³

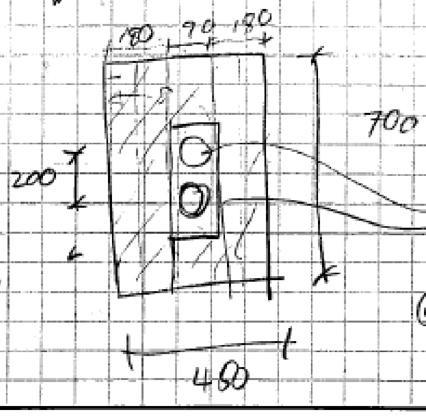
say 450mm wide ∴ d > 850mm

⇒ Reasonable ? No

∴ 2 bays not enough!

– Try – 4 Bays.

$M_b^* = 614$ kN.m $\phi M_n = 0.9 \times$



$A_{pt} = 13$ tendons $\times 2$

@ L1 – L3

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SLS check : use $\theta d = \frac{H}{300} / H$.

$= \frac{3810}{300} \times 100$ /3810

$= 0.33\%$.

and ; $R = 0.25$.

$\Rightarrow M_{B}^{*} = 170$ kN.m

$\Rightarrow \theta_{TOT} = \theta_{b} + \theta_{c}$ (only)

$\theta_b = 0.00192$

$\theta_c = 0.00146$

$\Rightarrow \theta_{TOT} = \theta_b + \theta_c = 0.0034 \approx 0.0033 \Rightarrow$ O.K!

Wind : $V_b \approx 1168$ kN $< V_{b\ seismic}$

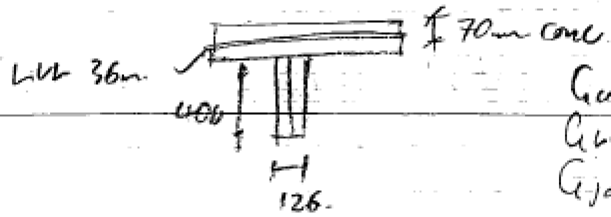
∴ Seismic governs!

Displacement-based design

DBD:

- 2 seismic bays.
- 8724 mm = L6
- Mass per floor
- G = 2.5 KPa. (incl. 0.5 kPa SDL)
- Q = 3.0 KPa – Basic live.

G :



G_{conc} = 1.68 KPa

G_{LVL} = 0.180 KPa

$G_{joist} = 400 \times 126 \times \frac{1.0}{1.2} \times 5$

= 0.210 KPa

$\therefore \; \Sigma G_{TOT} = 2.07$ KPa

$\therefore \; G_{SDL} = 0.4^{+}$ KPa

$\therefore \; G_{TOT} = \underline{2.5 \text{ KPa}}$

EQ:

$W_t = G + \psi_E Q$

$= 2.5 + 0.3 \times 3.0 = 3.4$ KPa

Primary beams, Secondary beams

$\Rightarrow \quad W_t = 3.4 \times 30 \times 17 + 34 \text{ kN} + 10.5 + 15.4 \text{ kN}$

$= 1,794$ kN.

$\Rightarrow \quad M_t = \underline{183 \text{ tonnes}}$

$\Rightarrow$ Assume ; same mass on every floor.

NZS1170.0 - general loading Std
IL = 3

Return = 1/1000 y e.q. design.

NZS 1170.5 - EQ code

=> Z = 0.22
=> D => deep soil.
=> R = 1.3

$\varepsilon_{q} = 6.2\%$

$\varepsilon_{el} = 5\%$

$\varepsilon_{hyst} = 2.5\%$ $\varepsilon_{hyst,con} = 1.2\%$

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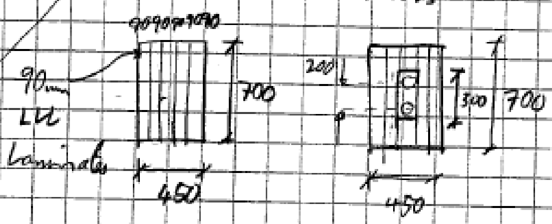
Summary:

→ First 2 Floors of tube

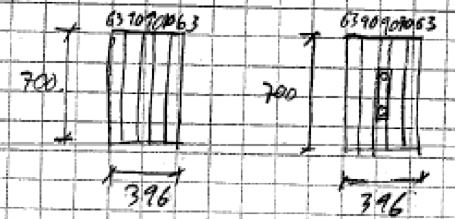
Columns | Beams | P.T. Tendons

~~L2, L3~~
~~L2, L3~~
L2, L3



2 x 10 - 0.6" Tendons
6-12 VSL - - .

~~L4, L5, Roof~~
~~L3, L4~~
L4, L5,

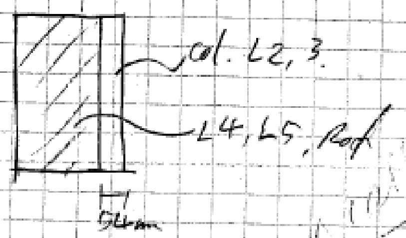


2 x 10 - 0.6" Tendons

NB: - offcuts should be used for primary beams. ⇒ 500mm waste per 90mm laminate
- still require 20mm steel plates on column faces.

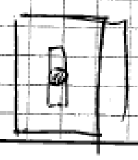
Level	Size	P.T.
L2	700x450	2 x 13 - 0.5"
L3	"	"
L4	700x 450	2 x 13 - 0.5
L5	"	
L6	700 x	1 x 13 - 0.5"
Roof	"	

Col.



L6, Roof : Plan
(same as L4, L5)

- 1 x 10 - 0.6" Tendons



Size floor Joist

Design

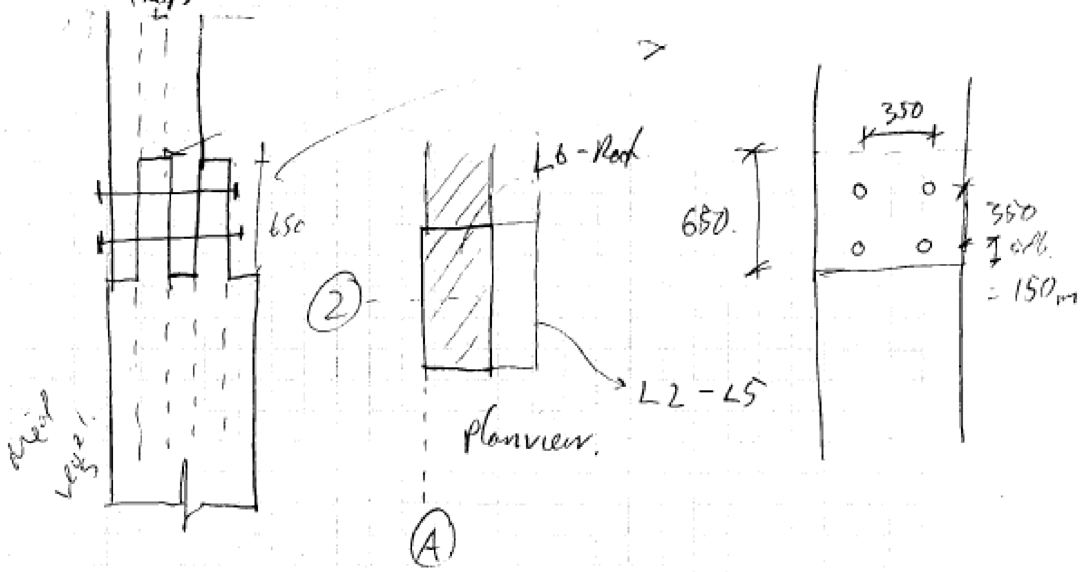
updated 20/8/09.

Try - L1/L2, in 700×450
- L3, L4 in 700×450 - reduce tendons
- L5-L6 in 700×270 - reduce timber

9×0.6

9×0.6

Level:	M^*	Size	Tendons:
L1 → L3	614	700×450	2 - 9 × 0.6" Tendons ○9 ○9
L4 → L5	525	700×450	2 - 8 × 0.6" Tendons ○8 ○8
L6 → L7 (Roof)	333	700×270.	1 - 9 × 0.6" Tendons ○9



$\approx V^* = 881$ kN - 5 cols

$V^*_{col} = 176$ kN

∴ Triple shear, $Q_{kl} \times 3$ $\quad Q_{kl} = Q_{kp} = 192 \cdot d^{1.5}$ or $6.45 \, l_e \, d$

$l_e = 2 \times 90 = 180$mm

Try M30s $\quad 192 \times d^{1.5} = 192 \times 30^{1.5} = 31.5$ kN $\quad$ or $\quad 6.45 \times 180 \times 30 = 34.8$.

$\frac{176}{3 \times 31.5} = 2$ Bolts

∴ 4 Bolts M30

Appendix 2: Case Study (1) Optimised TCC Floor design

The TCC floor design calculation was performed by Dr David Yeoh.

Connection distance for half span (in mm)			Conn		Conn		Conn			Summary
For 8543 mm span	End		1		2		3		Mid	6 connections along span
Distance between c/c connection		375		835		1250		1811.5		
Distance from end to centre connection				1210		2460		4271.5		
For 8124 mm span	Similar as 8543 mm span									6 connections along span
For 3912 mm span	End		1		Mid					2 connections along span
		400		1556						
				1956						

Design data:

DL inclusive self weight and superimposed		
DL	2.5	kPa
LL	3	kPa
Slab thickness	75	mm
Joist spacing	900	mm
LVL Truform Joist size	2 nos 63 x 400	
E for LVL	10.7	Gpa
Connection type	Plate 2 x 333 mm Mitek 1 mm thick	

Beams have been designed for ULS and SLS load combinations, checked for factored midspan point load of 2.7 kN, and vibration of 1 kN at midspan with less than 1 mm de

Also checked for long-term deflection. Long-term deflection in this case was not critical.

The shear in the connections governed the design instead of long-term deflection.

This is because the strength and stiffness of the plate connection is not as high as the notches.

Appendix 3: A Cost Comparison of the Three Timber Floors Systems

Construction Cost Comparison of different floor systems. (Note: delivered and in place cost)

	Types of Floor system	Rate (m2)	Remarks
1	Semi-prefabricated TCC floor system (m-section) 400 × 63mm LVL @ 1200mm centres with 17mm plywood, 65mm cast in-situ reinforced concrete topping, and square cut notches with M10 coach screws.	$160	Used by Smith (2008)-based on feasibility studies. Price of Concrete top was not included
2	Semi-prefabricated TCC floor system (m-section) 200 × 45mm LVL @ 1200mm centres with 17mm plywood, 50mm cast in-situ reinforced concrete topping, and square cut notches with M10 coach screws.	$216	Used by Newcombe (2010)-based on UC 2/3 scale experimental building
3	Semi-prefabricated TCC floor system (m-section) 400 × 63mm LVL @ 1200mm centres with 21 mm plywood, 65mm cast in-situ reinforced concrete topping, and with M10 diagonal fixed coach screws.	$245	Used by Menendez, A. Jesus (2010) –Napier building
4	Fully prefabricated double "T" floor with 400 × (2×63) LVL double joists @ 900mm centre. 75mm thick precast concrete with come with pressed toothed metal plate, wire-mesh and D12 top reinforcements.	$265	Used in this research -based on 2010 latest information.
5	Potius "M" section stressed skin system (excluding concrete topping, steel reinforcement, sound separation and vibration requirements)	$212+++	Quotation provided by Potius
6	300mm thick hallow-core with 90mm reinforced concrete topping	$180	Used in concrete building
7	0.9 thick Comflor 80 with 150mm reinforced concrete topping	$120	Used in Steel building

- The Potius floor system is found to have the highest cost of ($212 per cubic metre – excluding concrete topping and others)
- The equivalent precast concrete double tee systems of 2400mm wide - in place cost is around $115/m² to $125/m² (Rawlinson's, 2009).

Note: - Cost comparison for Floor systems

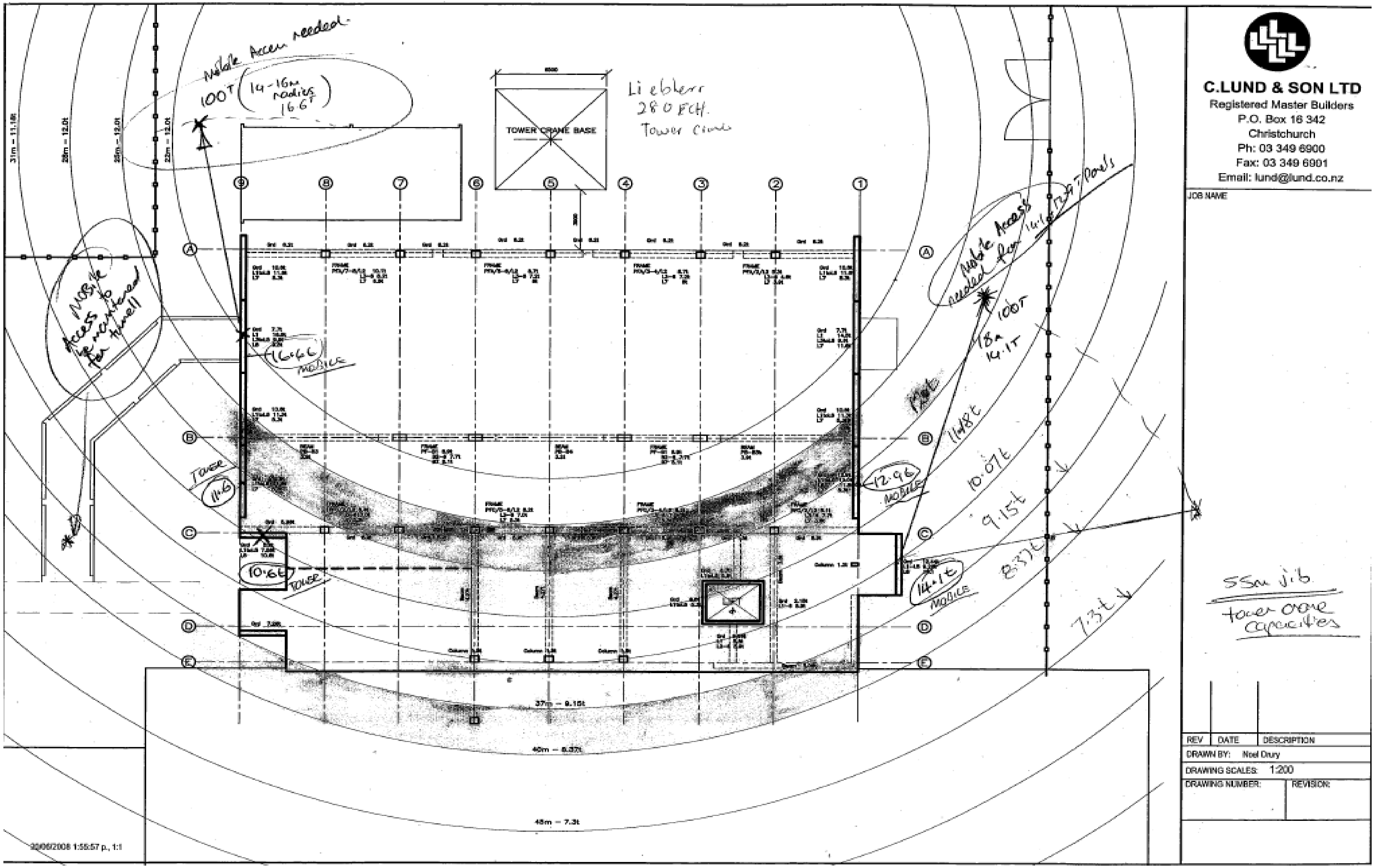
The total cost **($216 /m2)** for the floor system used in UC test Model is breakdown as follow:

1. Delivered cost- $162/m2
2. In-situ (50mm thick G30)concrete slab-$41.33/m2
3. In place (labour & crane)-$12.80/m2

The expected cost for the double "T" floor system proposed for case study (1) is **($265.00/m2**):-

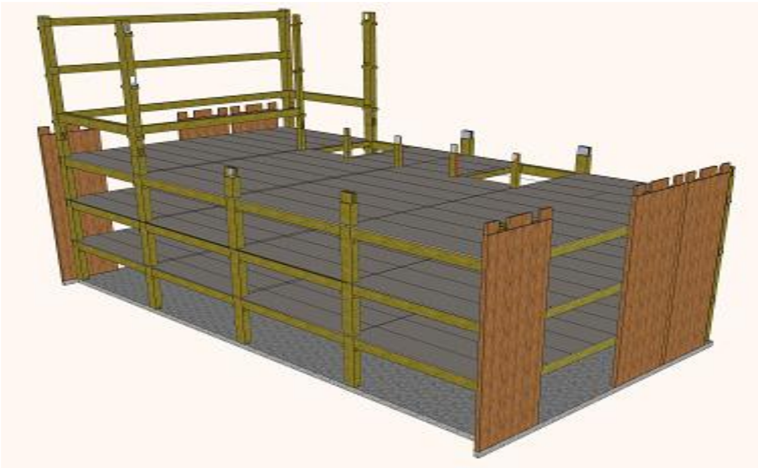
1. Delivered cost (LVL joists)-$157/m2
2. 75mm Precast concrete slab with steel wire mesh and top steel reinforcement (D12@ 300 centres)- (in place)-$66.00/m2
3. In place (tower crane)-$5.50/m2
4. Allow for supply, fixing of M16 coach screws@ 500 centre and grout patching to holes-$6.50/no

Appendix 4: Tower Crane Capacity Drawing
Courtesy of Stephen Mouat (C.LUND & SON LTD).



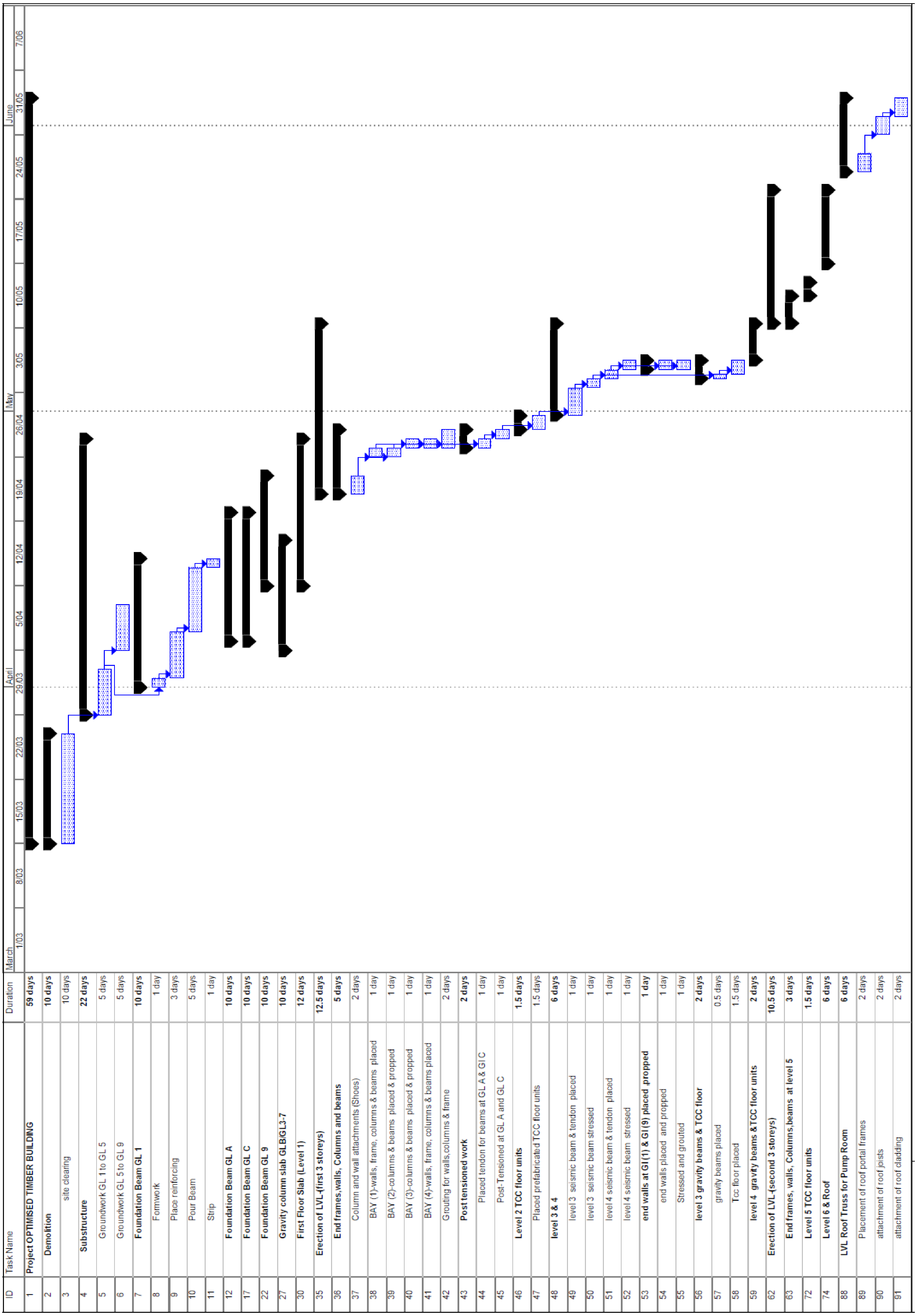
Appendix 5: Construction video for the six storey Pres-Lam Biological Sciences Building

A construction video for this Pres-Lam Biological Sciences building has been produced. To view this video please goes to the following link:



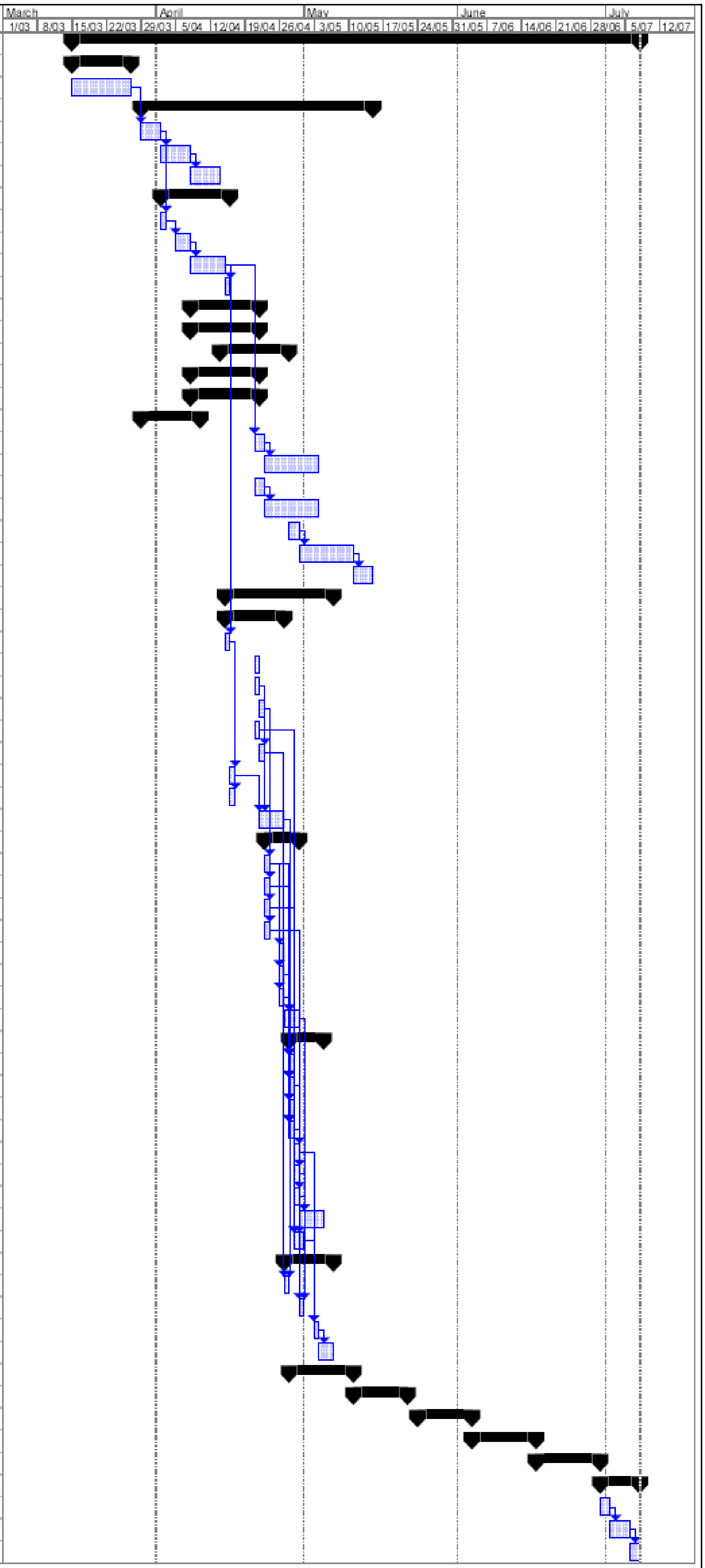
http://www.youtube.com/watch?v=xi_uMrRqsrQ

Appendix 6: Case study 1-Construction programme for optimised Pres-Lam building



Appendix 7: Case study 1-Construction programme for concrete building

ID	Task Name	Duration
1	PROJECT CONCRETE BUILDING	83 days
2	Demolition	10 days
3	Site clearing	10 days
4	Substructure	35 days
5	Groundwork S1	4 days
6	Groundwork S2	4 days
7	Groundwork S3	4 days
8	Foundation Beam GL 1	10 days
9	Formwork	1 day
10	Place reinforcing	3 days
11	Pour Beam	5 days
12	Strip	1 day
13	Foundation Beam GL A	10 days
18	Foundation Beam GL C	10 days
23	Foundation Beam GL 9	10 days
28	Gravity Column Slab GL B-3,B-4	10 days
31	Gravity Column Slab GL B-6,B-7	10 days
34	Stair well Slab and ground slab	10 days
37	Place reinforcing for first floor slab S1	2 days
38	Poor first floor slab	7 days
39	Place reinforcing for first floor slab S2	2 days
40	Poor first floor slab	7 days
41	Place reinforcing for first floor slab S3	2 days
42	Poor first floor slab	7 days
43	Strip Formwork	4 days
44	First floor	16 days
45	S1	8 days
46	GL 1 end walls	1 day
47	S1 GL A wall panels	1 day
48	S1 GL C wall panels	1 day
49	S1 GL B Frame	1 day
50	S1 GL C Frame	1 day
51	S1 GL B beam placed	1 day
52	Insitu column reo	1 day
53	Insitu column form	1 day
54	Insitu column pour	3 days
55	S2	5 days
56	S2 GL A wall panels	1 day
57	S2 GL B Columns	1 day
58	S2 GL C Frame 1	1 day
59	S2 GL C Frame 2	1 day
60	S2 GL B beam placed	1 day
61	Insitu column reo	1 day
62	Insitu column form	1 day
63	Insitu column pour	3 days
64	S3	5 days
65	GL 9 end walls	1 day
66	S3 GL A wall panels	1 day
67	S3 GL C wall panels	1 day
68	S3 GL C Frame	1 day
69	S3 GL B beam placed	1 day
70	Insitu column reo	1 day
71	Insitu column form	1 day
72	Insitu column pour	3 days
73	Prop and cast insitu joints	2 days
74	Flooring	8 days
75	S1 Flooring	1 day
76	S2 Flooring	1 day
77	S3 Flooring	1 day
78	Pour topping	3 days
79	Second floor	9 days
108	Third floor	9 days
137	Forth floor	9 days
166	Fifth floor	9 days
195	Sixth Floor	9 days
224	Roof Truss for Pump Room	6 days
225	Placement of roof portal frames	2 days
226	attachement of roof joists	2 days
227	attachement of roof cladding	2 days



Appendix 8: Cost of crane usage in the case study (1) buildings

Information about Tower crane hires (Rawlinson 2009) pages 4-121

1. The rates vary substantially depending on the period of hire.
2. Check market availability before pricing.
3. Prices exclude operator and fuel.

Tower crane use for concrete building	Qty	Units	cost	Sub-total
12T Tower Crane, electric saddle jib with the maximum radius (75m) and lift at maximum radius is 2.5 tonne.	17	Per week	$5,800	$98,600
Addition extra cost for Crane operator, dogman and fuel.	17	Per week	$4625	$78,625
Additional to base hire rates for foundations, including design and construction.	LS			$35,000
Additional to erection for tower crane, including transport, rigging, testing and commissioning.	LS			$35,000
Demobilisation, including dismantling, transport away from site.	LS			$35,000
Total cost for 12T Tower crane hire (17 weeks)				**$282,225**

Tower crane use for timber building	Qty	Units	cost	Sub-total
8T Tower Crane, electric saddle jib with the maximum radius (60m) and lift at maximum radius is 1.4 tonne.	12	Per week	$4500	$54,000
Addition extra cost for Crane operator, dogman and fuel.	12	Per week	$4575	$54,900
Additional to base hire rates for Foundations, including design and construction.	LS			$35,000
Additional to erection for tower crane, including transport, rigging, testing and commissioning.	LS			$35,000
Demobilisation, including dismantling, transport away from site.	LS			$35,000
Total cost for 8T Tower crane hire (12 weeks)				**$213,900**

Note: - From difference capacity of tower cranes used there is a cost saving of $ 68,325.

Appendix 9: Quotation for Post-tensioning works

Quotation received from Construction Techniques Ltd (previously known as BBR Contech NZ ltd).

Multi-story Post-Tensioned LVL Timber Structure (Press-Lam)					
	Description			**Unit**	**Cost**
Mobilising				LS	$ 1,200.00
Labour (operator & supervisor)				Day Rate	$ 900.00
Materials					
BBR Cona 1905 Stressing Heads				ea	$ 73.00
BBR Cona Stressing Wedges				ea	$ 2.70
End Bearing Anchorages/Plates				ea	TBC
Macalloy 1030 M32 Bar				m	$ 40.00
Macalloy 1030 M32 Nuts				ea	$ 24.00
Macalloy 1030 M32 Couplers				m	$ 49.00
12.7mm LLSS tensioning strand				Tonne	$ 1,800.00
Consumables				Day	$ 50.00
Plant					
3500kN Stressing Jack				Day Rate	$ 750.00
1000kN Stressing Jack				Day Rate	$ 250.00
Small Tools				Day Rate	$ 50.00
P & G					
Freight				LS	Cost + 15%
3500kN Jack Calibration				ea	$ 1,700.00
1000kN Jack Calibration				ea	$ 350.00
Pressure Gauge Calibration				ea	$ 250.00

Appendix 10: Case Study (1) Construction Costs Estimation for Biological Sciences Buildings

Appendix 10.1: Construction Costs Estimation for Optimised Timber Building

UoC Biological Sciences Building

ESTIMATE SUMMARY

STRUCTURE				
T	OPTIMISED TIMBER		$	8,867,967.10
			$	8,867,967.10
ELEMENT				
T02	SUBSTRUCTURE		$	228,920.00
T03	LVL FRAME		$	892,524.50
T04	FRAME POST-TENSIONING WORKS		$	34,089.60
T05	UPPER FLOORS		$	957,243.00
T06	ROOF		$	169,915.00
T07	EXTERIOR LVL WALLS		$	619,785.00
T08	EXTERIOR FINISH		$	493,845.00
T09	WINDOW AND EXTERIOR DOORS		$	1,017,850.00
T10	STAIRS AND BALUSTRADES		$	54,000.00
T11	INTERIOR WALLS		$	563,500.00
T12	INTERIOR DOORS		$	68,200.00
T13	FLOOR FINISHES		$	361,380.00
T14	CEILING FINISHES		$	249,250.00
T15	SANITARY PLUMBING		$	74,600.00
T16	HEATING AND VENTILATION SERVICES		$	1,382,700.00
T17	FIRE SERVICES		$	345,675.00
T18	ELECTRICAL SERVICES		$	599,170.00
T19	VERTICAL AND HORIZONTAL TRANSPORTATION		$	200,000.00
T20	SPECIAL SERVICES		$	50,000.00
T21	DRAINAGE		$	50,000.00
T22	EXTERNAL WORKS		$	4,840.00
T23	SUNDRIES		$	450,480.00
		Total	$	8,867,967.10
	PRELIMINARIES AND MARGIN	(13% of Total)	$	1,152,835.72
		Subtotal	$	10,020,802.82
		GRAND TOTAL	$	10,020,802.82

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T 02 STRUCTURE ELEMENT ***TIMBER* SUBSTRUCTURE**

Item	Item Description	Quantity	Unit		Rate		Amount
1	250 reinforced concrete ground floor slab on dpc on hardfill including excavavtion and disposal	72	m2	$	130.00	$	9,360.00
2	200 reinforced concrete ground floor slab on dpc on hardfill including excavation and disposal	725	m2	$	120.00	$	87,000.00
3	1200 x 600 deep reinforced concrete foundations including formwork, excavation and disposal to grid lines A and C	69	m	$	680.00	$	46,920.00
4	1400 x 1500 deep reinforced concrete foundations including formwork, excavation and disposal to grid lines 1 and 9	37	m	$	1,850.00	$	68,450.00
5	300 x 300 x 200 deep reinforced concrete pad foundations including formwaork, excavation and disposal	6	no	$	95.00	$	570.00
6	300 thick reinforced concrete raft foundations including excavation and disposal	58	m2	$	140.00	$	8,120.00
7	Reinforced concrete lift pit 1300 deep below of Level 0 slab including all excavation and disposal	1	LS	$	8,500.00	$	8,500.00
			Total for SUBSTRUCTURE			**$**	**228,920.00**

T 03 STRUCTURE ELEMENT ***TIMBER* LVL FRAME**

Item	Item Description	Quantity	Unit		Rate		Amount
8	700mm x 450mm LVL seismic columns , including corbels, fixings, predrill holes for (L2-L5)	151.8	m	$	910.00	$	138,138.00
9	700mm x 270mm LVL seismic columns , including corbels, fixings, predrill holes for (L6-Roof)	76.2	m	$	550.00	$	41,910.00
10	450x 396 LVL gravity	114.5	m	$	515.00	$	58,967.50
11	200 x 189 LVL posts	136	m	$	110.00	$	14,960.00
12	160 x 126 LVL posts	98	m	$	60.00	$	5,880.00
11	200 x 189 LVL posts	123	m	$	110.00	$	13,530.00
13	100x 100 x 9 SHS posts	2181	kg	$	6.00	$	13,086.00
14	700 x 450 LVL Seismic beams L2 to L5	256	m	$	910.00	$	232,960.00
15	700 x 270 LVL Seismic L6 & Roof beams	128	m	$	550.00	$	70,400.00
16	600 x 396 LVL Primary beams	138	m	$	690.00	$	95,220.00
17	600 x 270 LVL PB Roof	69	m	$	470.00	$	32,430.00
18	450 x 396 LVL gravity beams	67	m	$	515.00	$	34,505.00
19	450 x 270 LVL (L6-Roof beams)	33.3	m	$	360.00	$	11,988.00
20	240 x 126 LVL tie beams	115	m	$	90.00	$	10,350.00
21	200 x 126 LVL corridor beams	108	m	$	75.00	$	8,100.00
22	600 x 189 LVL edge beams	184	m	$	330.00	$	60,720.00
23	450 x 189 LVL edge roof beams	36.8	m	$	250.00	$	9,200.00
24	360 x 189 LVL plant room portals	161	m	$	200.00	$	32,200.00
25	Allow for splicing of columns, supply 4 no of M30 bolts and labours to fasten	15	no	$	100.00	$	1,500.00
26	Allow base connection plates for column, 4 no M25 holes hold down bolts , 8nos of 25mm holes for expoxied mild	15	no	$	200.00	$	3,000.00
27	M25 hold downs bolts cast in concrete base	60	no	$	38.00	$	2,280.00
28	Allow for Grouting of 8 no of 25 pipe sleeves (400mm depth)	48	m	$	25.00	$	1,200.00
			Total for FRAME			**$**	**892,524.50**

T 04 STRUCTURE ELEMENT ***TIMBER* POST-TENSIONING WORKS**

Item	Item Description	Quantity	Unit		Rate		Amount
29	Mobilisation	1	LS	$	1,200.00	$	1,200.00
30	Labour operator and supervisor	13	per day	$	900.00	$	11,700.00
31	BBR CONA 1905 stressing heads	42	no	$	72.00	$	3,024.00
32	BBR CONA stressing wedges	1116	no	$	2.60	$	2,901.60
33	End bearing anchorages plates	50	no	$	175.00	$	8,750.00
34	12.7mm LLSS tensioning strand (800kg/m3) for 10269m length	1.23	tonne	$	1,800.00	$	2,214.00
35	consumbles	17	day	$	50.00	$	850.00
	Plant						
36	1000kn stressing jack	6	day rate	$	250.00	$	1,500.00
37	small tools	17	day rate	$	50.00	$	850.00
	P & G						
38	Freight (cost x 15%)	1	LS	$	500.00	$	500.00
39	1000KN jack calibration	1	no	$	350.00	$	350.00

40	pressure calibration	1	no	$	250.00	$	250.00
				Total for POST-TENSIONING WORKS for FRAME		$	34,089.60

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T 05 STRUCTURE ELEMENT ***TIMBER* UPPER FLOOR**

Fully Prefabricated Double "TEE" TCC floor -400 x (2 x 63) LVL double joists @ 900mm centres with 75mm precast ; average panel Size 8.65m x 1.8 wide

41	Double LVL joists 400 x (2x63mm)@900 centre with pressed 333 Mitek plates shear connectors (supply and deliver)	3616	m2	$	189.00	$	683,424.00
42	75mm precast concrete topping include wiremesh, top rebars and supply, delivery and labour to place	3616	m2	$	66.00	$	238,656.00
43	Allow for Tower crane expenses to place	3616	m2	$	5.50	$	19,888.00
44	Allow for supply , fixing of M16 coach screws@ 500 centre and grout patching to holes	2350	no	$	6.50	$	15,275.00
				Total For TIMBER UPPER FLOOR		$	957,243.00

T 06 STRUCTURE ELEMENT ***TIMBER* ROOF**

45	Colorsteel Trimdek 400 0.55 corrugated steel roofing on building paper on netting on purlins on rafters	445	m2	$	135.00	$	60,075.00
46	1.5 butyl rubber on 17.5 Cp-D grade ply sarking on 150 roof framing	409	m2	$	180.00	$	73,620.00
47	1.5 butyl rubber to concrete slab	60	m	$	70.00	$	4,200.00
48	250 x 300 x 0.75 thick colorsteel fascia gutter	36	m	$	70.00	$	2,520.00
49	150 x 175 x 0.75 thick colorsteel fascia gutter	80	m	$	70.00	$	5,600.00
50	0.55 Colorstell parapet flashing to main roof including profiled timber blocking and all grooves in concrete	73	m	$	100.00	$	7,300.00
51	Colorsteel downpipes	158	m	$	50.00	$	7,900.00
52	Paniton 9 Vitra panel on battens to soffits	87	m2	$	100.00	$	8,700.00
				Total For ROOF		$	169,915.00

T 07 STRUCTURE ELEMENT ***TIMBER* EXTERNAL LVL WALLS**

53	252 wide LVL shear walls with paint on 9 Exotec on rainscreen cavity system	567	m2	$	975.00	$	552,825.00
54	base connection plates; 12 no. holes for M32 epoxied mild steel bars; with 20 nos, M25 x 400 holding-down bolts in the base plates; casting into concrete	6	no	$	2,200.00	$	13,200.00
55	Allow for Grouting of 12 no of 32 pipe sleeves (400mm depth)	28.8	m	$	25.00	$	720.00
56	Allow for splicing of walls, supply 3 sets of 8 nos M30 bolts and labours to fasten	6	no	$	600.00	$	3,600.00
57	2 sets of 4 nos. of M32mm MacAlloy bars -holding down bolts; casting into concrete base	6	no	$	400.00	$	2,400.00
58	M32mm dia. x 11.8m length Macalloy 1030 bars	72	no	$	472.00	$	33,984.00
59	MacAlloy 1030 -washer and nuts	72	no	$	24.00	$	1,728.00
60	MacAlloy 1030 32mm couplers	72	no	$	49.00	$	3,528.00
61	End bearing anchorages plates	12	no	$	200.00	$	2,400.00
62	Allow labour to place MacAlloy Bars	6	days	$	900.00	$	5,400.00
				Total for EXTERNAL SHEAR WALLS		$	619,785.00

STRUCTURE ELEMENT ***TIMBER* EXTERIOR FINISH**

63	Paint on 9 Exotec on rainscreen cavity system on 100 wall framing including R2.6 insulation and paint on 13 Gibboard and skirting	1572	m2	$	270.00	$	424,440.00
64	Paint on 9 Exotec on rainscreen cavity system on 100 wall framing to roof parapet panels comprising 450 thick x 1250 wide top piece and 200 thick x 550 high upstand	36	m	$	850.00	$	30,600.00
65	Paint on 9 Exotec on rainscreen cavity system on 100 wall framing to columns	23	m	$	325.00	$	7,475.00
66	Profiled 0.55 Diamond LT7 cladding on building paper on 100 timber framing to timber portals (Plant room)	241	m2	$	130.00	$	31,330.00
				Total for EXTERIOR FINISH		$	493,845.00

T 09 STRUCTURE ELEMENT ***TIMBER* WINDOW AND EXTERNAL DOORS**

67	135 Flushglaze aluminium curtain walling system with double glazed 'E' type glazing	1381	m2	$	650.00	$	897,650.00
68	Extra value for pilkington Armourclad obscure outer panel (East walls-toilets and stairwell, North wall at floors)	452	m2	$	50.00	$	22,600.00
69	Pair of double glazed commercial section aluminium doors including frame and hardware	3	no	$	4,000.00	$	12,000.00
70	Double glazed commercial section aluminium windows (west and east elevations)	72	m2	$	500.00	$	36,000.00

71	25 timber reveal linings 400 wide to windows on North Elevation (Levels 2-6)	496	m	$	100.00	$	49,600.00
				Total For WINDOWS AND EXTERIOR DOORS		$	**1,017,850.00**
UoC Biological Sciences Building							
T 10	STRUCTURE ELEMENT	***TIMBER* STAIRS AND BALUSTRADES**					
72	Internal timber stair including stainless handrail and glass balustrading to one level	27	m	$	2,000.00	$	54,000.00
				Total For STAIRS AND BALUSTRADES		$	**54,000.00**
T 11	STRUCTURE ELEMENT	***TIMBER* INTERIOR WALLS**					
73	Paint on Fyreline both sides of 100 timber wall framing including skirting and acoustic insulation	615	m2	$	200.00	$	123,000.00
74	Paint on 13 Gibboard both sides of 300 timber wall framing including R2.6 insulation (spandreal panel)	164	m2	$	170.00	$	27,880.00
75	Paint on 9 Exotec one side and paint on 13 Gibboard the other side on 100 wall framing including skirting and insulation	1685	m2	$	240.00	$	404,400.00
76	Paint to LVL walls	548	m2	$	15.00	$	8,220.00
				Total For INTERIOR WALLS		$	**563,500.00**
T 12	STRUCTURE ELEMENT	***TIMBER* INTERIOR DOORS**					
77	Pair of solid core paint grade doors including frame, hardware and finish	5	no	$	2,000.00	$	10,000.00
78	Unequal Pair of solid core paint grade doors including frame, hardware and finish	21	no	$	1,800.00	$	37,800.00
79	Single solid core paint grade door including frame, hardware and finish	17	no	$	1,200.00	$	20,400.00
				Total For INTERIOR DOORS		$	**68,200.00**
T 13	STRUCTURE ELEMENT	***TIMBER* FLOOR FINISHES**					
80	Carpet tiles direct stuck	3660	m2	$	80.00	$	292,800.00
81	Sheet vinyl with welded joints and coved edge including hydropoxy to concrete	685	m2	$	90.00	$	61,650.00
82	Stair nosing with black rubber insert	231	m	$	30.00	$	6,930.00
				Total For FLOOR FINISHES		$	**361,380.00**
T 14	STRUCTURE ELEMENT	***TIMBER* CEILING FINISHES**					
83	Mineral fibre ceiling tiles in exposed suspension grid	3660	m2	$	55.00	$	201,300.00
84	Paint on 13 Gibboard on metal suspension grid	685	m2	$	70.00	$	47,950.00
				Total For CEILING FINISHES		$	**249,250.00**
T 15	STRUCTURE ELEMENT	***TIMBER* SANITARY PLUMBING**					
85	Water Supply	1	LS	$	2,000.00	$	2,000.00
86	Toilet pan and cistern complete with water and waste services	12	no	$	2,600.00	$	31,200.00
87	Wash hand basin complete with water and waste services	12	no	$	1,300.00	$	15,600.00
88	Cleaners sink complete with water and waste services	6	no	$	1,800.00	$	10,800.00
89	Shower complete with tempering valve, water and waste services	6	no	$	2,500.00	$	15,000.00
				Total For SANITARY PLUMBING		$	**74,600.00**
T 16	STRUCTURE ELEMENT	***TIMBER* HEATING AND VENTILATION SERVICES**					
90	Fully ducted air conditioning system	4609	m2	$	300.00	$	1,382,700.00
				Total For HEATING AND VENTILATION SERVICES		$	**1,382,700.00**
T 17	STRUCTURE ELEMENT	***TIMBER* FIRE SERVICES**					
91	Automatic fire sprinkler sytem incorporating a manual fire alarm system and an automatic smoke/heat detection system	4609	m2	$	75.00	$	345,675.00
				Total For FIRE SERVICES		$	**345,675.00**
T 18	STRUCTURE ELEMENT	***TIMBER* ELECTRICAL SERVICES**					
92	Electric power and lighting including submains and swithboards	4609	m2	$	130.00	$	599,170.00

					Total For ELECTRICAL SERVICES $	**599,170.00**

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T 19 STRUCTURE ELEMENT ***TIMBER* VERTICAL AND HORIZONTAL TRANSPORTATION**

93	LIFT serving seven storeys (exluding shaft) (say)	1	LS	$ 200,000.00	$	200,000.00
					Total For VERTICAL AND HORIZONTAL TRANSPORTATION $	**200,000.00**

T 20 STRUCTURE ELEMENT ***TIMBER* SPECIAL SERVICES**

94	Voice and data/comms system (say)	1	LS	$ 50,000.00	$	50,000.00
95	Audio/visual system (excluded)					
					Total For SPECIAL SERVICES $	**50,000.00**

T 21 STRUCTURE ELEMENT ***TIMBER* DRAINAGE**

96	Sewer and storm water drainage (say)	1	LS	$ 50,000.00	$	50,000.00
					Total For DRAINAGE $	**50,000.00**

T 22 STRUCTURE ELEMENT ***TIMBER* EXTERNAL WORKS**

97	Concrete paving	44	m2	$ 110.00	$	4,840.00
					Total For EXTERNAL WORKS $	**4,840.00**

T 23 STRUCTURE ELEMENT ***TIMBER* SUNDRIES**

98	300 x 50 parallelogram aluminium louvre system on fabricated steel support structure (north elevation)	712	m2	$ 550.00	$	391,600.00
99	Maintenance platform 700 wide (north elevation)	184	m	$ 200.00	$	36,800.00
100	Handrail (to maintenance platform) (north elevation)	184	m	$ 120.00	$	22,080.00
101	curtains and Blinds (exculded)					
102	Loose furniture and equipment (excluded)					
					Total For SUNDRIES $	**450,480.00**
					Total For OPTIMISED TIMBER BUILDING $	**8,867,967.10**
					TOTAL $	**8,867,967.10**
	PRELIMINARIES AND MARGIN				(13.00% of Total) $	**1,152,835.72**
					Subtotal $	**10,020,802.82**
					GRAND TOTAL For OPTIMISED TIMBER BUILDING $	**10,020,802.82**

Appendix 10.1.2 Spreadsheet for Taking-off Quantity for Optimised Pres-Lam Building

Optimise Design for Multi-storey Timber Biological Science building

Beam	For	Location	width (m)	depth (m)	Length (m)	nos	Vol(M3)
Roof beam	**Seismic frame**	(GL-A/GL1-3 & GLC/GL1-3)	0.27	0.7	7.982	2	3.017
L6 beam	ditto	ditto	0.27	0.7	7.982	2	3.017
L5 beam	ditto	ditto	0.45	0.7	7.982	2	5.029
L4 beam	ditto	ditto	0.45	0.7	7.982	2	5.029
L3 beam	ditto	ditto	0.45	0.7	7.982	2	5.029
L2 beam	ditto	ditto	0.45	0.7	7.982	2	5.029
Roof beam	ditto	(GL-A/GL3-7 & GLC/GL3-7)	0.27	0.7	7.324	4	5.537
L6 beam	ditto	ditto	0.27	0.7	7.324	4	5.537
L5 beam	ditto	ditto	0.45	0.7	7.324	4	9.228
L4 beam	ditto	ditto	0.45	0.7	7.324	4	9.228
L3 beam	ditto	ditto	0.45	0.7	7.324	4	9.228
L2 beam	ditto	ditto	0.45	0.7	7.324	4	9.228
Roof beam	ditto	(GL-A/GL7-9 & GLC/GL7-9)	0.27	0.7	7.632	2	2.885
L6 beam	ditto	ditto	0.27	0.7	7.632	2	2.885
L5 beam	ditto	ditto	0.45	0.7	7.632	2	4.808
L4 beam	ditto	ditto	0.45	0.7	7.632	2	4.808
L3 beam	ditto	ditto	0.45	0.7	7.632	2	4.808
L2 beam	ditto	ditto	0.45	0.7	7.632	2	4.808
Roof beam	**Primary beam**	(GL3, GL 5, GL 7/GL A-GL B)	0.378	0.6	11.450	3	7.791
L6 beam	ditto	ditto	0.378	0.6	11.450	3	7.791
L5 beam	ditto	ditto	0.378	0.6	11.450	3	7.791
L4 beam	ditto	ditto	0.378	0.6	11.450	3	7.791
L3 beam	ditto	ditto	0.378	0.6	11.450	3	7.791
L2 beam	ditto	ditto	0.378	0.6	11.450	3	7.791
Roof beam	ditto	(GL3, GL 5, GL 7/GL B-GL C)	0.378	0.45	5.604	3	2.860
L6 beam	ditto	ditto	0.378	0.45	5.604	3	2.860
L5 beam	ditto	ditto	0.378	0.45	5.604	3	2.860
L4 beam	ditto	ditto	0.378	0.45	5.604	3	2.860
L3 beam	ditto	ditto	0.378	0.45	5.604	3	2.860
L2 beam	ditto	ditto	0.378	0.45	5.604	3	2.860
Roof beam	**Tie beam**	(GL4 & GL 6/GL B-GL C)	0.378	0.45	5.604	2	1.906
L6 beam	ditto	ditto	0.378	0.45	5.604	2	1.906
L5 beam	ditto	ditto	0.378	0.45	5.604	2	1.906
L4 beam	ditto	ditto	0.378	0.45	5.604	2	1.906
L3 beam	ditto	ditto	0.378	0.45	5.604	2	1.906
L2 beam	ditto	ditto	0.378	0.45	5.604	2	1.906
Roof beam	ditto	(GLB /GL 3- 4 & GL 6-7)	0.27	0.45	3.562	2	0.866
L6 beam	ditto	ditto	0.27	0.45	3.562	2	0.866
L5 beam	ditto	ditto	0.27	0.45	3.562	2	0.866
L4 beam	ditto	ditto	0.27	0.45	3.562	2	0.866
L3 beam	ditto	ditto	0.27	0.45	3.562	2	0.866
L2 beam	ditto	ditto	0.27	0.45	3.562	2	0.866
Edge Beam							
Roof beam	EB	GL 1 & GL 9/A-C	0.189	0.6	17.644	2	4.002
L6 beam	ditto	ditto	0.189	0.6	17.608	2	3.993
L5 beam	ditto	ditto	0.189	0.6	17.608	2	3.993
L4 beam	ditto	ditto	0.189	0.6	17.608	2	3.993
L3 beam	ditto	ditto	0.189	0.6	17.500	2	3.969
L2 beam	ditto	ditto	0.189	0.6	17.500	2	3.969
Cantilever Beam							
Roof beam	CB	At GL 3,4,5,6,7 & 8/C-C'	0.378	0.45	2.200	6	2.245
L6 beam	ditto	ditto	0.378	0.45	2.200	6	2.245
L5 beam	ditto	ditto	0.378	0.45	2.200	6	2.245
L4 beam	ditto	ditto	0.378	0.45	2.200	6	2.245
L3 beam	ditto	ditto	0.378	0.45	2.200	6	2.245
L2 beam	ditto	ditto	0.378	0.45	2.200	6	2.245
					Total Beam (m3)		**217.064**

Total Building Height 22.86m (assume stump 200mm)

Column		Location	width (m)	depth (m)	Length (m)	nos	Vol(M3)
Level 1 to level 6	Frame	GLA & GLC	0.45	0.7	18.85	10	59.378
Level 1 to level 6	Gravity	GLB	0.27	0.4	18.85	5	10.179
Level 6 to level R	Frame	GLA & GLC	0.45	0.7	3.81	10	12.002
Level 6 to level R	Gravity	GLB	0.27	0.4	3.81	5	2.057
Level 1 to 4	Support	Along GL C'	0.18	0.2	11.23	6	2.426
Level 4 to Roof	Support	Along GL C'	0.18	0.2	11.43	6	2.469
					Total column (m3)		**86.041**

Wall Panel -Total height 23.86m (assume stump 200mm)

Wall	Location	width (m)	depth (m)	Length (m)	nos	Vol(M3)
Level 1 to level 4	GL1 & GL 9/ GL A-C	4.000	0.252	11.23	6	67.919
Level 4 to level R	GL1 & GL 9/ GL A-C	4.000	0.252	12.43	6	75.177
				Total Wall (m3)		**143.096**

Prefrabricated plywood floor approx 7.5m longx 2.4m wide

Floor joist	Location	width (m)	depth (m)	Length (m)	nos	Vol(M3)
Level 2 to Roof	GL1-GL3	0.063 x 2	0.4	8.543	96	41.334
	GL3-GL5	0.063 x 2	0.4	8.124	78	31.937
	GL5-GL7	0.063 x 2	0.4	8.124	78	31.937
	GL7-GL9	0.063 x 2	0.4	8.543	96	41.334
Level 2 to Roof	Gl C to C'	0.063 x 2	0.4	19.56	18	17.745
				Total floor joist (m3)		**164.288**
				Total Project LVL (m3)		**610.489**

	Length (m)	Vol(M3)
Total Project LVL	137.628	99.138

Appendix 10.2: Construction Costs Estimation for Concrete Building

UoC Biological Sciences Building

ESTIMATE SUMMARY

STRUCTURE				
C	CONCRETE		$	8,453,458.00
			$	8,453,458.00
ELEMENT				
C02	SUBSTRUCTURE		$	230,890.00
C03	CONCRETE FRAME		$	752,318.00
C04	STRUCTURAL WALLS		$	136,110.00
C05	UPPER FLOORS		$	723,550.00
C06	ROOF		$	169,915.00
C07	EXTERIOR WALLS AND EXTERIOR FINISH		$	1,053,510.00
C09	WINDOW AND EXTERIOR DOORS		$	1,017,850.00
C10	STAIRS AND BALUSTRADES		$	72,900.00
C11	INTERIOR WALLS		$	460,120.00
C12	INTERIOR DOORS		$	68,200.00
C13	FLOOR FINISHES		$	361,380.00
C14	CEILING FINISHES		$	249,250.00
C15	SANITARY PLUMBING		$	74,600.00
C16	HEATING AND VENTILATION SERVICES		$	1,382,700.00
C17	FIRE SERVICES		$	345,675.00
C18	ELECTRICAL SERVICES		$	599,170.00
C19	VERTICAL AND HORIZONTAL TRANSPORTATION		$	200,000.00
C20	SPECIAL SERVICES		$	50,000.00
C21	DRAINAGE		$	50,000.00
C22	EXTERNAL WORKS		$	4,840.00
C23	SUNDRIES		$	450,480.00
		Total	$	8,453,458.00
	PRELIMINARIES AND MARGIN	(13% of Total)	$	1,098,949.54
		Subtotal	$	9,552,407.54
		GRAND TOTAL	$	9,552,407.54

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Item	Item Description	Quantity	Unit	Rate	Amount
C 02	STRUCTURE ELEMENT *CONCRETE* **SUBSTRUCTURE**				
1	300 reinforced concrete ground floor slab on dpc on hardfill including excavavtion and disposal	72	m2	$ 140.00	$ 10,080.00
2	200 reinforced concrete ground floor slab on dpc on hardfill including excavation and disposal	725	m2	$ 120.00	$ 87,000.00
3	1200 x 600 deep reinforced concrete foundations including formwork, excavation and disposal to grid lines A and C	69	m	$ 680.00	$ 46,920.00
4	1500 x 1400 deep reinforced concrete foundations including formwork, excavation and disposal to grid lines 1 and 9	37	m	$ 1,850.00	$ 68,450.00
5	300 thick reinforced concrete raft foundations including excavation and disposal	71	m2	$ 140.00	$ 9,940.00
6	Reinforced concrete lift pit 1300 deep below of Level 0 slab including all excavation and disposal	1	LS	$ 8,500.00	$ 8,500.00
				Total for SUBSTRUCTURE	**$ 230,890.00**
C 03	STRUCTURE ELEMENT *CONCRETE* **FRAME**				
8	Reinforced concrete columns (400x 800)	72	m	$ 575.00	$ 41,400.00
9	Reinforced concrete columns (400x 500)	269	m	$ 370.00	$ 99,530.00
10	Reinforced concrete beams (400x 800)	248	m	$ 450.00	$ 111,600.00
11	Reinforced concrete beams (400x 600deep)	790	m	$ 380.00	$ 300,200.00
12	Reinforced concrete beams (300x 510 deep)	209	m	$ 360.00	$ 75,240.00
13	Insitu reinforced concrete beams (300x 510 deep)	60	m	$ 390.00	$ 23,400.00
14	Main roof steelwork (LSC)	15658	kg	$ 6.00	$ 93,948.00
15	Miscellaneous plates and cleats	1000	kg	$ 7.00	$ 7,000.00
				Total for FRAME	**$ 752,318.00**
C 04	STRUCTURE ELEMENT *CONCRETE* **STRUCTURAL WALLS**				
16	300 reinforced precast concrete lift shart walls	349	m2	$ 390.00	$ 136,110.00
				Total for STRUCTURAL WALLS	**$ 136,110.00**
C 05	STRUCTURE ELEMENT *CONCRETE* **UPPER FLOOR**				
17	90 reinforced concrete topping on 300 Dycore suspended floor system	2574	m2	$ 180.00	$ 463,320.00
18	90 reinforced concrete topping on 200 Dycore suspended floor system	1046	m2	$ 160.00	$ 167,360.00
19	65 reinforced concrete topping on Unispan suspended floor system	645	m2	$ 130.00	$ 83,850.00
20	140 reinforced concrete suspended floor system	41	m2	$ 220.00	$ 9,020.00
				Total For UPPER FLOOR	**$ 723,550.00**
C 06	STRUCTURE ELEMENT *CONCRETE* **ROOF**				
21	Colorsteel Trimdek 400 0.55 corrugated steel roofing on building paper on netting on purlins on rafters	445	m2	$ 135.00	$ 60,075.00
22	1.5 butyl rubber on 17.5 Cp-D grade ply sarking on 150 roof framing	409	m2	$ 180.00	$ 73,620.00
23	1.5 butyl rubber to concrete slab	60	m2	$ 70.00	$ 4,200.00
24	250 x 300 x 0.75 thick colorsteel fascia gutter	36	m	$ 70.00	$ 2,520.00
25	150 x 175 x 0.75 thick colorsteel fascia gutter	80	m	$ 70.00	$ 5,600.00
26	0.55 Colorstell parapet flashing to main roof including profiled timber blocking and all grooves in concrete	73	m	$ 100.00	$ 7,300.00
27	Colorsteel downpipes	158	m	$ 50.00	$ 7,900.00
28	Panit on 9 Vitra panel on battens to soffits	87	m2	$ 100.00	$ 8,700.00
				Total For ROOF	**$ 169,915.00**

C 07 STRUCTURE ELEMENT *CONCRETE* **EXTERNAL WALLS AND EXTERIOR**

29	Paint on Thermomass 310 renforced precast concrete shear wall panels	1540	m2	$	490.00	$	754,600.00
30	Paint on 200 renforced precast concrete shear wall panels	95	m2	$	320.00	$	30,400.00
31	Paint on 200 renforced precast spandreal panels including 50 insulation	164	m2	$	330.00	$	54,120.00
32	Reinforced precast concrete roof parapet panels comprising 450 thick x 1250 wide top piece and 200 thick x 550 high upstand	36	m	$	1,200.00	$	43,200.00
33	Paint on 9 vitro panel on rainscreen cavity system on 100 wall framing including R2.6 insulation and paint on 13 Gibboard and skirting	518	m2	$	270.00	$	139,860.00
34	Profiled 0.55 Dimond LT7 cladding on building paper on 100 timber framing to steel portals (plant room)	241	m2	$	130.00	$	31,330.00
	Total for EXTERNAL WALLS AND EXTERIOR FINISH					$	**1,053,510.00**

C 09 STRUCTURE ELEMENT *CONCRETE* **WINDOW AND EXTERNAL DOORS**

35	135 Flushglaze aluminium curtain walling system with double glazed 'E' type glazing	1381	m2	$	650.00	$	897,650.00
36	Extra value for pilkington Armourclad obscure outer panel (East walls-toilets and stairwell, North wall at floors)	452	m2	$	50.00	$	22,600.00
37	Pair of double glazed commercial section aluminium doors including frame and hardware	3	no	$	4,000.00	$	12,000.00
38	Double glazed commercial section aluminium windows (west and east elevations)	72	m2	$	500.00	$	36,000.00
39	25 timber reveal linings 400 wide to windows on North Elevation (Levels 2-6)	496	m	$	100.00	$	49,600.00
	Total For WINDOWS AND EXTERIOR DOORS					$	**1,017,850.00**

C 10 STRUCTURE ELEMENT *CONCRETE* **STAIRS AND BALUSTRADES**

40	Internal reinforced precast concrete stair including stainless handrail and glass balustrading to one level	27	m	$	2,700.00	$	72,900.00
	Total For STAIRS AND BALUSTRADES					$	**72,900.00**

C 11 STRUCTURE ELEMENT *CONCRETE* **INTERIOR WALLS**

41	Paint on Fyreline both sides of 100 wall framing including skirting and acoustic insulation	1466	m2	$	200.00	$	293,200.00
42	Paint on 9 Exotec one side and paint on 13 Gibboard the other side on 100 wall framing including skirting and insulation	643	m2	$	240.00	$	154,320.00
44	Paint to precast concrete walls	840	m2	$	15.00	$	12,600.00
	Total For INTERIOR WALLS					$	**460,120.00**

C 12 STRUCTURE ELEMENT *CONCRETE* **INTERIOR DOORS**

45	Pair of solid core paint grade doors including frame, hardware and finish	5	no	$	2,000.00	$	10,000.00
46	Unequal Pair of solid core paint grade doors including frame, hardware and finish	21	no	$	1,800.00	$	37,800.00
47	Single solid core paint grade door including frame, hardware and finish	17	no	$	1,200.00	$	20,400.00
	Total For INTERIOR DOORS					$	**68,200.00**

C 13 STRUCTURE ELEMENT *CONCRETE* **FLOOR FINISHES**

48	Carpet tiles direct stuck	3660	m2	$	80.00	$	292,800.00
49	Sheet vinyl with welded joints and coved edge including hydropoxy to concrete	685	m2	$	90.00	$	61,650.00
50	Stair nosing with black rubber insert	231	m	$	30.00	$	6,930.00
	Total For FLOOR FINISHES					$	**361,380.00**

C 14 STRUCTURE ELEMENT *CONCRETE* **CEILING FINISHES**

51	Mineral fibre ceiling tiles in exposed suspension grid	3660	m2	$	55.00	$	201,300.00
52	Paint on 13 Gibboard on metal suspension grid	685	m2	$	70.00	$	47,950.00
	Total For CEILING FINISHES					$	**249,250.00**

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C 15	STRUCTURE ELEMENT	*CONCRETE* **SANITARY PLUMBING**					
53	Water Supply (say)	1	LS	$	2,000.00	$	2,000.00
54	Toilet pan and cistern complete with water and waste services	12	no	$	2,600.00	$	31,200.00
55	Wash hand basin complete with water and waste services	12	no	$	1,300.00	$	15,600.00
56	Cleaners sink complete with water and waste services	6	no	$	1,800.00	$	10,800.00
57	Shower complete with tempering valve, water and waste services	6	no	$	2,500.00	$	15,000.00
				Total For SANITARY PLUMBING		**$**	**74,600.00**
C 16	STRUCTURE ELEMENT	*CONCRETE* **HEATING AND VENTILATION SERVICES**					
58	Fully ducted air conditioning system	4609	m2	$	300.00	$	1,382,700.00
				Total For HEATING AND VENTILATION SERVICES		**$**	**1,382,700.00**
C 17	STRUCTURE ELEMENT	*CONCRETE* **FIRE SERVICES**					
59	Automatic fire sprinkler sytem incorporating a manual fire alarm system and an automatic smoke/heat detection system	4609	m2	$	75.00	$	345,675.00
				Total For FIRE SERVICES		**$**	**345,675.00**
C 18	STRUCTURE ELEMENT	*CONCRETE* **ELECTRICAL SERVICES**					
60	Electric power and lighting including submains and swithboards	4609	m2	$	130.00	$	599,170.00
				Total For ELECTRICAL SERVICES		**$**	**599,170.00**
C 19	STRUCTURE ELEMENT	*CONCRETE* **VERTICAL AND HORIZONTAL TRANSPORTATION**					
61	LIFT serving seven storeys (exluding shaft) (say)	1	LS	$	200,000.00	$	200,000.00
				Total For VERTICAL AND HORIZONTAL TRANSPORTATION		**$**	**200,000.00**
C 20	STRUCTURE ELEMENT	*CONCRETE* **SPECIAL SERVICES**					
62	Voice and data/comms system (say)	1	LS	$	50,000.00	$	50,000.00
63	Audio/visual system (excluded)						
				Total For SPECIAL SERVICES		**$**	**50,000.00**
C 21	STRUCTURE ELEMENT	*CONCRETE* **DRAINAGE**					
64	Sewer and storm water drainage (say)	1	LS	$	50,000.00	$	50,000.00
				Total For DRAINAGE		**$**	**50,000.00**
C 22	STRUCTURE ELEMENT	*CONCRETE* **EXTERNAL WORKS**					
65	Concrete paving	44	m2	$	110.00	$	4,840.00
				Total For EXTERNAL WORKS		**$**	**4,840.00**
C 23	STRUCTURE ELEMENT	*CONCRETE* **SUNDRIES**					
66	300 x 50 parallelogram aluminium louvre system on fabricated steel support structure (north elevation)	712	m2	$	550.00	$	391,600.00
67	Maintenance platform 700 wide (north elevation)	184	m	$	200.00	$	36,800.00
68	Handrail (to maintenance platform) (north elevation)	184	m	$	120.00	$	22,080.00
69	curtains and Blinds (exculded)						
70	Loose furniture and equipment (excluded)						
				Total For SUNDRIES		**$**	**450,480.00**
				Total For CONCRETE BUILDING		**$**	**8,453,458.00**
				TOTAL		**$**	**8,453,458.00**
	PRELIMINARIES AND MARGIN			(13.00% of Total)		**$**	**1,098,949.54**
				Subtotal		**$**	**9,552,407.54**
				GRAND TOTAL For CONCRETE BUILDING		**$**	**9,552,407.54**

Appendix 10.3: Construction Costs Estimation for Steel Building

UoC Biological Sciences Building

ESTIMATE SUMMARY

STRUCTURE				
S	STEEL		$	8,571,397.00
			$	8,571,397.00
ELEMENT				
S 02	SUBSTRUCTURE		$	231,550.00
S 03	STEEL FRAME		$	1,628,917.00
S 04	UPPER FLOORS		$	645,600.00
S 05	ROOF		$	169,915.00
S 06	EXTERIOR WALLS AND EXTERIOR FINISH		$	428,595.00
S 07	WINDOW AND EXTERIOR DOORS		$	1,017,850.00
S 08	STAIRS AND BALUSTRADES		$	72,900.00
S 09	INTERIOR WALLS		$	539,775.00
S 10	INTERIOR DOORS		$	68,200.00
S 11	FLOOR FINISHES		$	361,380.00
S 12	CEILING FINISHES		$	249,250.00
S 13	SANITARY PLUMBING		$	74,600.00
S 14	HEATING AND VENTILATION SERVICES		$	1,382,700.00
S 15	FIRE SERVICES		$	345,675.00
S 16	ELECTRICAL SERVICES		$	599,170.00
S 17	VERTICAL AND HORIZONTAL TRANSPORTATION		$	200,000.00
S 18	SPECIAL SERVICES		$	50,000.00
S 19	DRAINAGE		$	50,000.00
S 20	EXTERNAL WORKS		$	4,840.00
S 21	SUNDRIES		$	450,480.00
		Total	$	8,571,397.00
	PRELIMINARIES AND MARGIN	(13% of Total)	$	1,114,281.61
		Subtotal	$	9,685,678.61
		GRAND TOTAL	$	9,685,678.61

UoC Biological Sciences Building

Item	Item Description	Quantity	Unit	Rate		Amount
S 02	STRUCTURE ELEMENT	*STEEL* **SUBSTRUCTURE**				
1	300 reinforced concrete ground floor slab on dpc on hardfill including excavavtion and disposal	72	m2	$ 140.00	$	10,080.00
2	200 reinforced concrete ground floor slab on dpc on hardfill including excavation and disposal	725	m2	$ 120.00	$	87,000.00
3	1200 x 600 deep reinforced concrete foundations including formwork, excavation and disposal to grid lines A and C	69	m	$ 680.00	$	46,920.00
4	1500 x 1400 deep reinforced concrete foundations including formwork, excavation and disposal to grid lines 1 and 9	37	m	$ 1,850.00	$	68,450.00
5	400X400X200 reinforced concrete pad foundations including formworks, excavation and disposal	6	no	$ 110.00	$	660.00
5	300 thick reinforced concrete raft foundations including excavation and disposal	71	m2	$ 140.00	$	9,940.00
6	Reinforced concrete lift pit 1300 deep below of Level 0 slab including all excavation and disposal	1	LS	$ 8,500.00	$	8,500.00
				Total for SUBSTRUCTURE	$	**231,550.00**
S 03	STRUCTURE ELEMENT	*STEEL* **FRAME**				
7	Steelworks in columns	69656	kg	$ 5.50	$	383,108.00
8	Steelworks in beams	138199	kg	$ 5.50	$	760,094.50
9	Steelworks in braces	22823	kg	$ 5.50	$	125,526.50
10	Main roof steelworks (LSC)	15658	kg	$ 6.00	$	93,948.00
11	Miscellanous plates and cleats	20000	kg	$ 7.00	$	140,000.00
12	Extra value for fire rating steel work	2104	m2	$ 60.00	$	126,240.00
				Total for FRAME	$	**1,628,917.00**
S 04	STRUCTURE ELEMENT	*STEEL* **UPPER FLOOR**				
13	150 reinforced concrete topping on 0.9 comflor 80 suspended floor system	4304	m2	$ 150.00	$	645,600.00
				Total For UPPER FLOOR	$	**645,600.00**
S 05	STRUCTURE ELEMENT	*STEEL* **ROOF**				
14	Colorsteel Trimdek 400 0.55 corrugated steel roofing on building paper on netting on purlins on rafters	445	m2	$ 135.00	$	60,075.00
15	1.5 butyl rubber on 17.5 Cp-D grade ply sarking on 150 roof framing	409	m2	$ 180.00	$	73,620.00
16	1.5 butyl rubber to concrete slab	60	m2	$ 70.00	$	4,200.00
17	250 x 300 x 0.75 thick colorsteel fascia gutter	36	m	$ 70.00	$	2,520.00
18	150 x 175 x 0.75 thick colorsteel fascia gutter	80	m	$ 70.00	$	5,600.00
19	0.55 Colorstell parapet flashing to main roof including profiled timber blocking and all grooves in concrete	73	m	$ 100.00	$	7,300.00
20	Colorsteel downpipes	158	m	$ 50.00	$	7,900.00
21	Panit on 9 Vitra panel on battens to soffits	87	m2	$ 100.00	$	8,700.00
				Total For ROOF	$	**169,915.00**
S 06	STRUCTURE ELEMENT	*STEEL* **EXTERNAL WALLS AND EXTERIOR FINISH**				
22	Profiled 0.55 Dimond LT7 on Rondo cavity battens on building paper on 92 x 1.15 steel studs framing including R2.6 insulation and paint on 13 Gibboards and skirting internally	1808	m2	$ 200.00	$	361,600.00
23	Profiled 0.55 Diamond LT7 cladding on building paper on 92 x 1.15 steel studs framing to steel portals (plant room)	241	m2	$ 120.00	$	28,920.00

24	Paint on 9 Exotec on Rondo cavity battens on building paper on 92 x 1.15 steel studs framing to roof parapet panels comprising 450 thick x 1250 top piece and 200 thick x 550 high upstand	36	m2	$	850.00	$	30,600.00
25	Paint on 9 Exotec on Rondo cavity battens on building paper on 92 x 1.15 steel studs framing to columns	23	m2	$	325.00	$	7,475.00
					Total for EXTERNAL WALLS AND EXTERIOR FINISH	$	**428,595.00**

UoC Biological Sciences Building

S 07	STRUCTURE ELEMENT	*STEEL* **WINDOW AND EXTERNAL DOORS**					
26	135 Flushglaze aluminium curtain walling system with double glazed 'E' type glazing	1381	m2	$	650.00	$	897,650.00
27	Extra value for pilkington Armourclad obscure outer panel (East walls-toilets and stairwell, North wall at floors)	452	m2	$	50.00	$	22,600.00
28	Pair of double glazed commercial section aluminium doors including frame and hardware	3	no	$	4,000.00	$	12,000.00
29	Double glazed commercial section aluminium windows (west and east elevations)	72	m2	$	500.00	$	36,000.00
30	25 timber reveal linings 400 wide to windows on North Elevation (Levels 2-6)	496	m	$	100.00	$	49,600.00
					Total For WINDOWS AND EXTERIOR DOORS	$	**1,017,850.00**
S 08	STRUCTURE ELEMENT	*STEEL* **STAIRS AND BALUSTRADES**					
31	Internal reinforced precast concrete stair including stainless handrail and glass balustrading to one level	27	m	$	2,700.00	$	72,900.00
					Total For STAIRS AND BALUSTRADES	$	**72,900.00**
S 09	STRUCTURE ELEMENT	*STEEL* **INTERIOR WALLS**					
32	Paint on Fyreline both sides of 92 x 0.75 steel stud framing including skirting and acoustic insulation	615	m2	$	190.00	$	116,850.00
33	Paint on 13 Gibboard both sides of 150 x 0.75 thick steel stud framing including skirting and R2.6 insulation (spandrel panel)	164	m2	$	150.00	$	24,600.00
34	Paint on 9 Exotec one side and paint on 13 Gibboard the other side on 92 x 0.75 steel stud framing including skirting and insulation	843	m2	$	235.00	$	198,105.00
35	Paint on 9 Exotec one side and paint on 13 Gibboard the other side on 92 x 0.75 steel stud framing including skirting and insulation	852	m2	$	235.00	$	200,220.00
					Total For INTERIOR WALLS	$	**539,775.00**
S 10	STRUCTURE ELEMENT	*STEEL* **INTERIOR DOORS**					
36	Pair of solid core paint grade doors including frame, hardware and finish	5	no	$	2,000.00	$	10,000.00
37	Unequal Pair of solid core paint grade doors including frame, hardware and finish	21	no	$	1,800.00	$	37,800.00
38	Single solid core paint grade door including frame, hardware and finish	17	no	$	1,200.00	$	20,400.00
					Total For INTERIOR DOORS	$	**68,200.00**
S 11	STRUCTURE ELEMENT	*STEEL* **FLOOR FINISHES**					
39	Carpet tiles direct stuck	3660	m2	$	80.00	$	292,800.00
40	Sheet vinyl with welded joints and coved edge including hydropoxy to concrete	685	m2	$	90.00	$	61,650.00
41	Stair nosing with black rubber insert	231	m	$	30.00	$	6,930.00
					Total For FLOOR FINISHES	$	**361,380.00**
S 12	STRUCTURE ELEMENT	*STEEL* **CEILING FINISHES**					
42	Mineral fibre ceiling tiles in exposed suspension grid	3660	m2	$	55.00	$	201,300.00
43	Paint on 13 Gibboard on metal suspension grid	685	m2	$	70.00	$	47,950.00
					Total For CEILING FINISHES	$	**249,250.00**

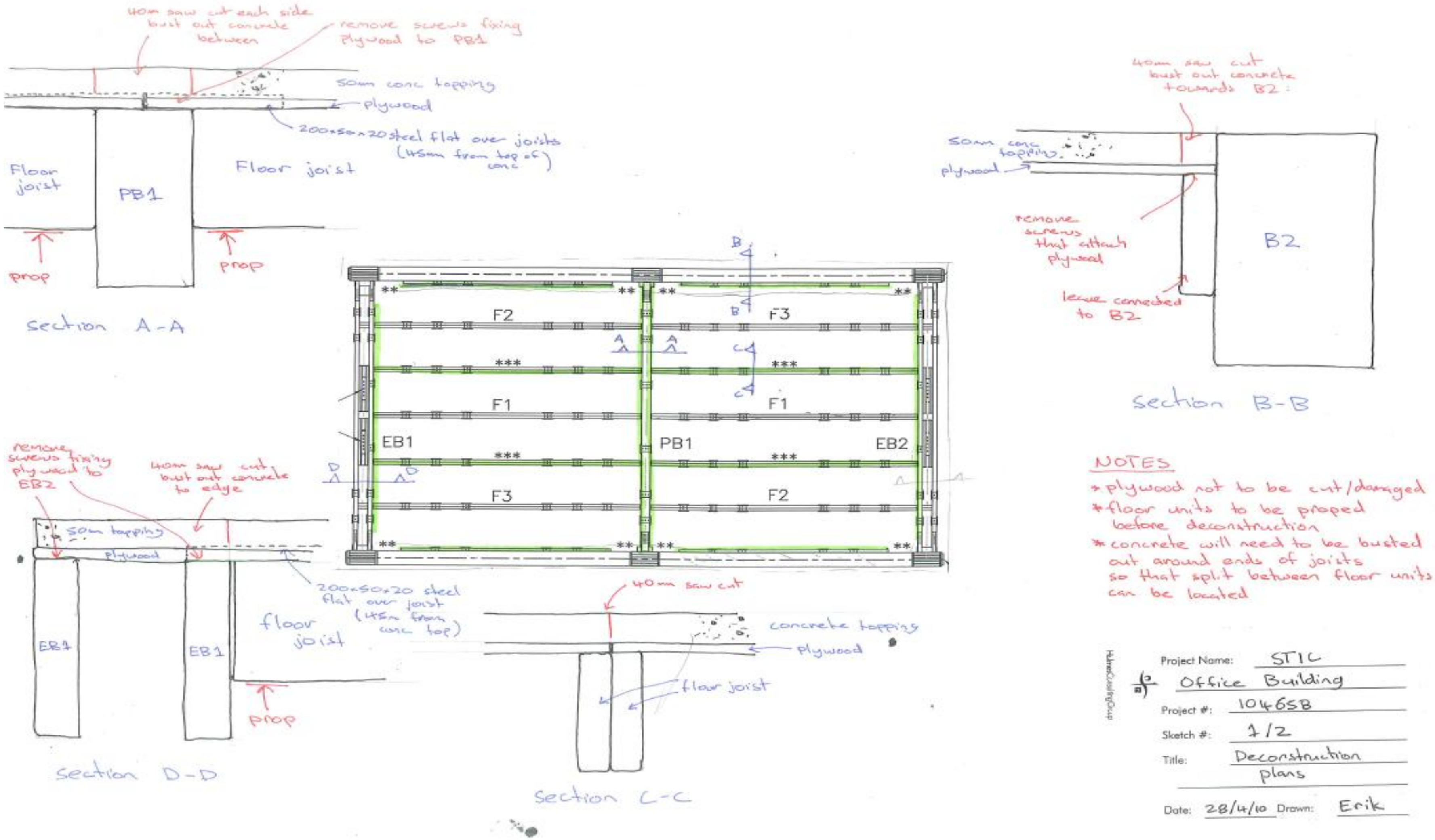
S 13	STRUCTURE ELEMENT	*STEEL* **SANITARY PLUMBING**					
44	Water Supply (say)	1	LS	$	2,000.00	$	2,000.00
45	Toilet pan and cistern complete with water and waste services	12	no	$	2,600.00	$	31,200.00
46	Wash hand basin complete with water and waste services	12	no	$	1,300.00	$	15,600.00
47	Cleaners sink complete with water and waste services	6	no	$	1,800.00	$	10,800.00
48	Shower complete with tempering valve, water and waste services	6	no	$	2,500.00	$	15,000.00
					Total For SANITARY PLUMBING	**$**	**74,600.00**

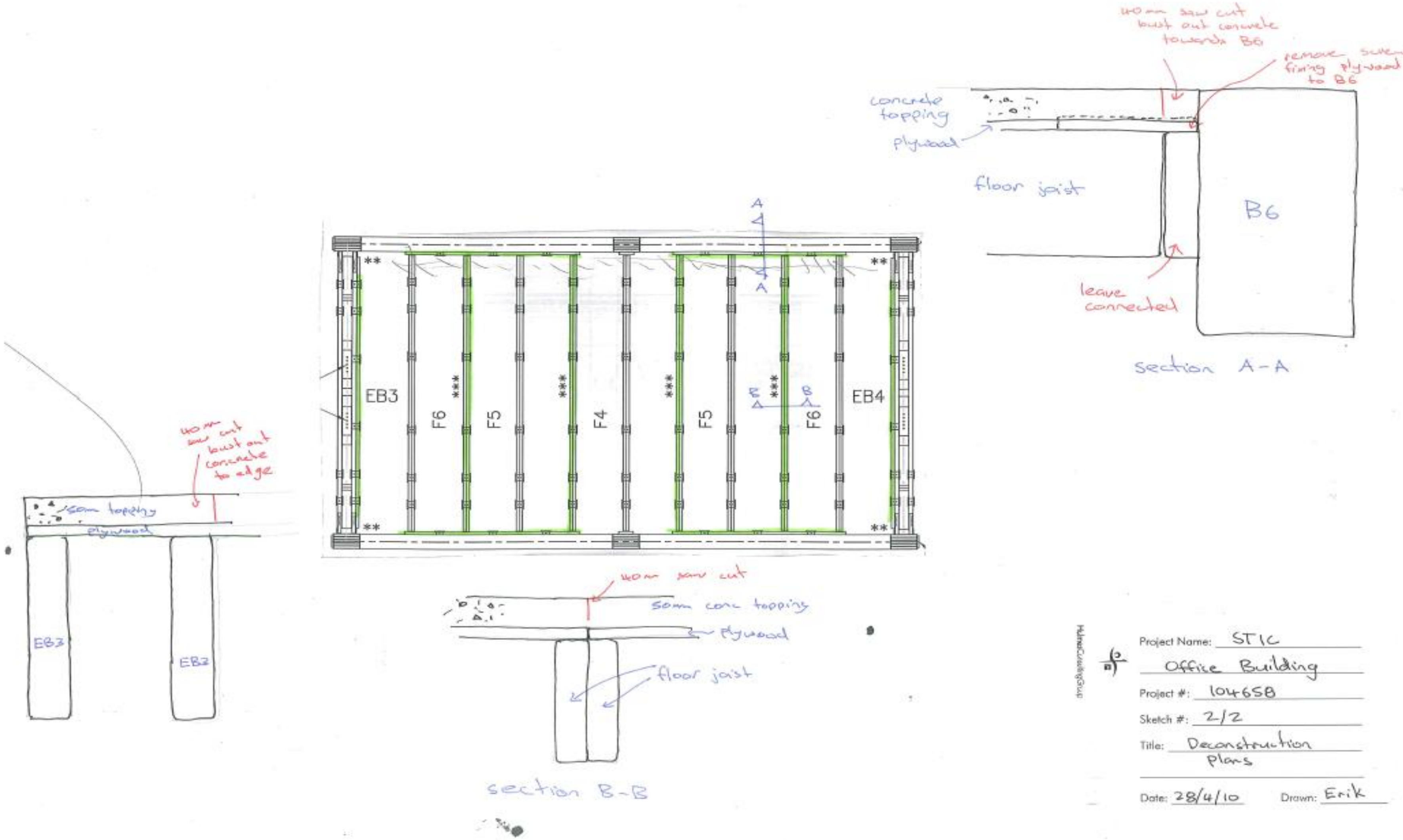
UoC Biological Sciences Building

S 14	STRUCTURE ELEMENT	*STEEL* **HEATING AND VENTILATION SERVICES**					
49	Fully ducted air conditioning system	4609	m2	$	300.00	$	1,382,700.00
					Total For HEATING AND VENTILATION SERVICES	**$**	**1,382,700.00**
S 15	STRUCTURE ELEMENT	*STEEL* **FIRE SERVICES**					
50	Automatic fire sprinkler sytem incorporating a manual fire alarm system and an automatic smoke/heat detection system	4609	m2	$	75.00	$	345,675.00
					Total For FIRE SERVICES	**$**	**345,675.00**
S 16	STRUCTURE ELEMENT	*CONCRETE* **ELECTRICAL SERVICES**					
60	Electric power and lighting including submains and swithboards	4609	m2	$	130.00	$	599,170.00
					Total For ELECTRICAL SERVICES	**$**	**599,170.00**
S17	STRUCTURE ELEMENT	*CONCRETE* **VERTICAL AND HORIZONTAL TRANSPORTATION**					
61	LIFT serving seven storeys (exluding shaft) (say)	1	LS	$	200,000.00	$	200,000.00
					Total For VERTICAL AND HORIZONTAL TRANSPORTATION	**$**	**200,000.00**
S 18	STRUCTURE ELEMENT	*STEEL* **SPECIAL SERVICES**					
62	Voice and data/comms system (say)	1	LS	$	50,000.00	$	50,000.00
63	Audio/visual system (excluded)						
					Total For SPECIAL SERVICES	**$**	**50,000.00**
S 19	STRUCTURE ELEMENT	*STEEL* **DRAINAGE**					
64	Sewer and storm water drainage (say)	1	LS	$	50,000.00	$	50,000.00
					Total For DRAINAGE	**$**	**50,000.00**
S 20	STRUCTURE ELEMENT	*STEEL* **EXTERNAL WORKS**					
65	Concrete paving	44	m2	$	110.00	$	4,840.00
					Total For EXTERNAL WORKS	**$**	**4,840.00**
S 21	STRUCTURE ELEMENT	*STEEL* **SUNDRIES**					
66	300 x 50 parallelogram aluminium louvre system on fabricated steel support structure (north elevation)	712	m2	$	550.00	$	391,600.00
67	Maintenance platform 700 wide (north elevation)	184	m	$	200.00	$	36,800.00
68	Handrail (to maintenance platform) (north elevation)	184	m	$	120.00	$	22,080.00
69	curtains and Blinds (exculded)						
70	Loose furniture and equipment (excluded)						
					Total For SUNDRIES	**$**	**450,480.00**
					Total For STEEL BUILDING	**$**	**8,571,397.00**

Appendix 11: Sketches of Deconstruction of the Experimental Building

This set of sketches was produced by the engineers (Holmes-Mr Richard Seville)




40mm saw cut
bust out concrete
towards B6
remove screws
fixing plywood
to B6
concrete
topping
plywood
floor joist
B6
leave
connected
section A-A
A
A
EB3
F6
F5
F4
F5
F6
EB4
B
B
40mm
saw cut
bust out
concrete
to edge
50mm topping
plywood
EB3
EB2
40mm saw cut
50mm conc topping
plywood
floor joist
section B-B
Project Name: STIC
Office Building
Project #: 104658
Sketch #: 2/2
Title: Deconstruction
Plans
Date: 28/4/10
Drawn: Erik

Appendix 12: Deconstruction Cost of Experimental Building

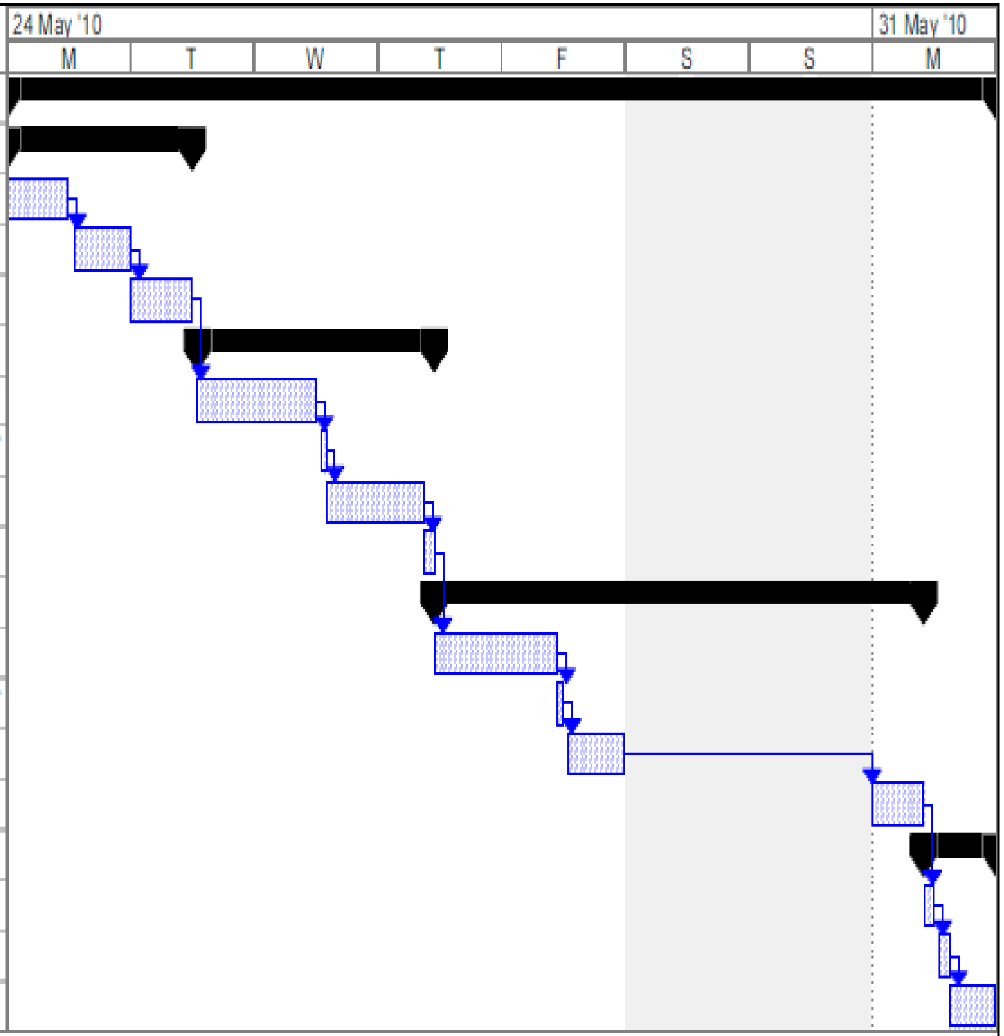
UoC STIC experimental 2 storey Building

DECONSTRUCTION COSTS

Item	Item Description	Quantity	Unit	Rate		Amount
1	Mobilisation & enabling works	6	LS	45	$	270.00
2	To supply labours and supervisor to marked lines for Suspended floors	4	hrs	45	$	180.00
	TEMPORARY SUPPORTS					
3	To supply materials for temporary bracing & propping (market rate)	1	LS	500	$	500.00
4	To supply labours and supervisor for temporary supports- (setting up and dismantled props)	16	hrs	45	$	720.00
5	Mobile scaffold (2.4 x 1.2 x 4m)	1	no	120	$	120.00
	CONCRETE CUTTING					
6	Allow for tools, equipment & labour for concrete cutting on suspended floors	1	LS	1000	$	1,000.00
	PT WORKS					
7	Allow for mobilisation, P& G, plants and consumables	1	no	1000	$	1,000.00
8	Labour for destressing & to removed tendons	14	hr	45	$	630.00
	CHIPPED OFF PERIMETER CONCRETE, REMOVED SCREWS & OTHER MISCELLANOUS					
9	Allow for supply small tools , drill and concrete breaker	3	day	100	$	300.00
10	Allow for supply labours for chipping out perimeter concrete, removed screws and other miscellaneous works.	24	hr	45	$	1,080.00
	Labour					
11	Labour for dismantled the floor units,beams, columns and walls	32	hr	45	$	1,440.00
12	labour overhead & downtime	12	hr	45	$	540.00
	CRANE					
13	Allow for 8 tonnes mobile crane (market rates)	20	hr	120	$	2,400.00
14	add extra for delievery & pickup pervisit	3	no	80	$	240.00
				Total costs	**$**	**10,420.00**

Appendix 13 : Programme for Deconstruction of the Experimental Building

ID	Task Name	Duration
1	**STIC project deconstruction**	**6 days**
2	**Prepartion works**	**1.5 days**
3	mobilisation	4 hrs
4	Floors marking at level 2 and level 3	4 hrs
5	Propping at level 1 and 2	4 hrs
6	**At level 3**	**1.88 days**
7	cutting , removing of floor panels at level 3	1 day
8	Dismantling level 3 Post-tensioned tendons	1 hr
9	diassemble level 3 beams	4 hrs
10	Temporary bracing for columns and walls	2 hrs
11	**At level 2**	**1.88 days**
12	cutting , removing of floor panels at level 2	1 day
13	Dismantling level 3 Post-tensioned tendons	1 hr
14	diassemble level 2 beams	4 hrs
15	Temporary bracing for columns and walls	2 hrs
16	**East-west frames and walls**	**0.75 days**
17	Diassembled east frame, walls and edges beams	2 hrs
18	Diassembled west frame, walls and edges beams	2 hrs
19	storage and clear site	2 hrs



Appendix 14: Design, Sketches and Drawings for Remediation works for STIC Building

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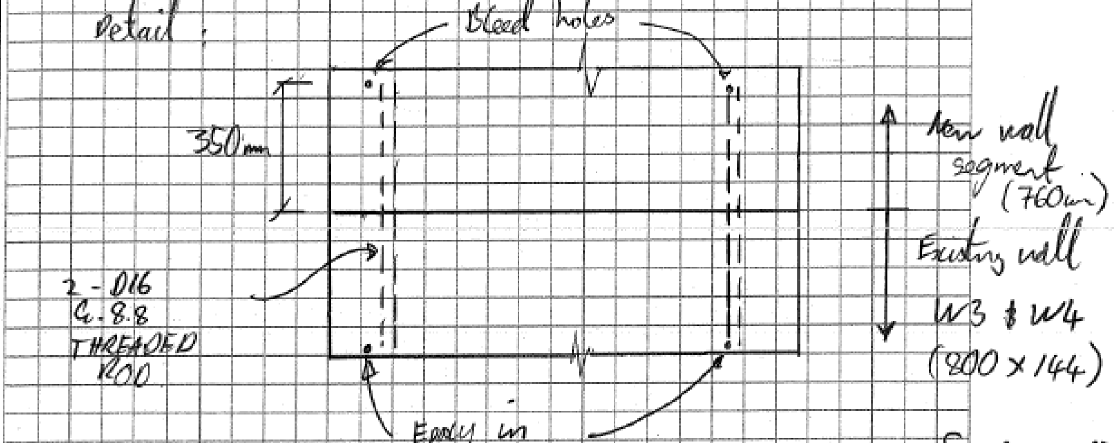
Project: STIC Building - Rebuild
Subject: Remediation works
By: M. P. Newcombe
Date: 24/05/2010 Page 1 of 4

Civil Engineering Department

Wall Extension:

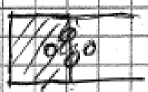
Detail:



Use 16mm thread rod; $\phi N_n = 0.9 \times A_s f_y$ [TDG, 2007 pg.326]

$\phi N_n = 138$ kN. - BAR yield.

- check wood failure;



$A_n \approx 144000$ mm $k_1 = 1.0$

$\therefore \phi N_{failure} = 144000 \times 30 \times 1.0$

$= 432$ kN > 138

- Check pullout:

$Q_k = 166$ kN

$\therefore k_g = 1.0$

$\therefore \phi N_{pullout} = 0.8 \times 166 = 133 \approx 138$ O.K!

Moment Capacity:

$\phi M_n \simeq 2 \times 133 \times (800 - 200) = 160$ kN.m

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Project:
Subject:
By: MPN
Date: 24/05/2010 Page 2 of 4

Civil Engineering Department

Shear Strength;

- see over page: using Johansen theory [TDG, pp 309; or EC5]

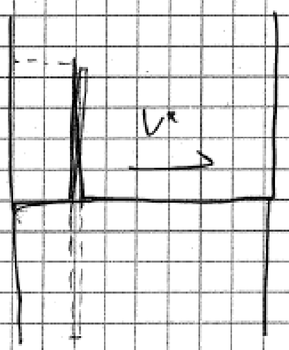
$\Rightarrow \phi V_n = 0.8 \times 73 = 58.4$ kN/bar

- steel failure;

$\phi V_n = 0.8 \times 0.8 \times 157 \times 880 = 88 > 58$

$\therefore \phi V_{n_{TOT}} = 4 \times 58.4 = \underline{234 \text{ kN}}$

Also, check splitting;



ϕV_n 308×350 × 144 × 1 MPa

$= 40$ kN

$\phi V_{n,TOT} = \underline{80 \text{ kN}}$

NB: - PT will provide shear & Moment capacity.

$M_{pt} \simeq 5 \times 0.6 \times 99 \times 1560 (800 - 100) = \underline{324 \text{ kN.m}}$

$V_{pt} \simeq 0.1 \times F_{pt} = 0.1 \times 5 \times 99 \times 1560 \times 0.6 = \underline{46 \text{ kN}}$

conservative (for steel)

$\phi M_{n_{TOT}} \simeq \underline{484 \text{ kN.m}}$ $\phi V_{n_{TOT}} \simeq \underline{126 \text{ kN}}$

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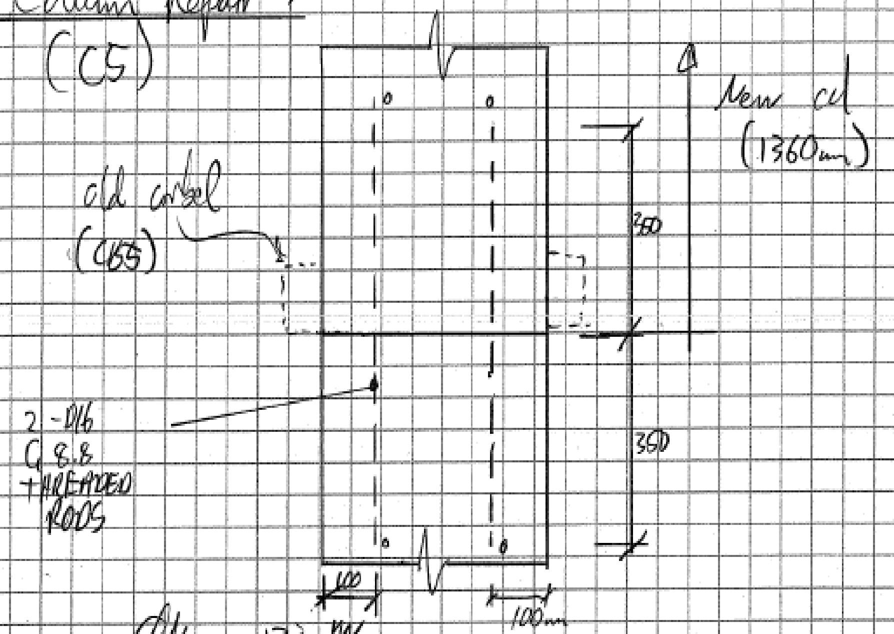
Project: ______
Subject: ______
By: M.D. NEWCOMBE
Date: 24/05/2010 Page 3 of 4

Civil Engineering Department

Column Repair:
(C5)



$\phi N_n = 133$ kN

Moment capacity:

$\phi M_n = 2 \times 133 \times (400-200) = 53$ kN.m

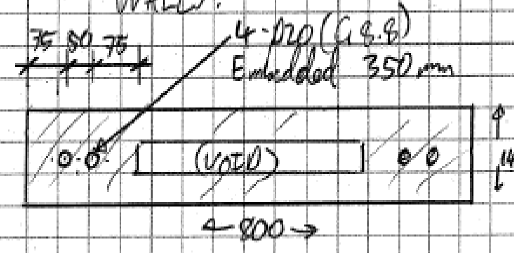
Shear strength:

$\phi V_n = 0.8 \times 264 \times 360 \times 1 = 68$ kN

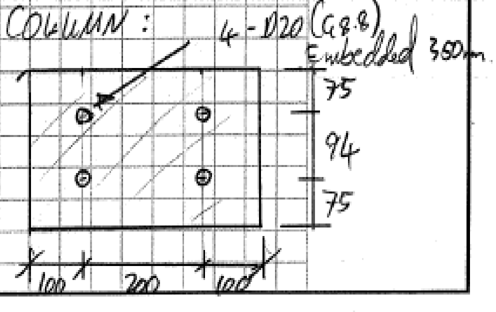
(conservative).

SECTIONS:

WALLS:



COLUMN:



MPN
24/05/2010

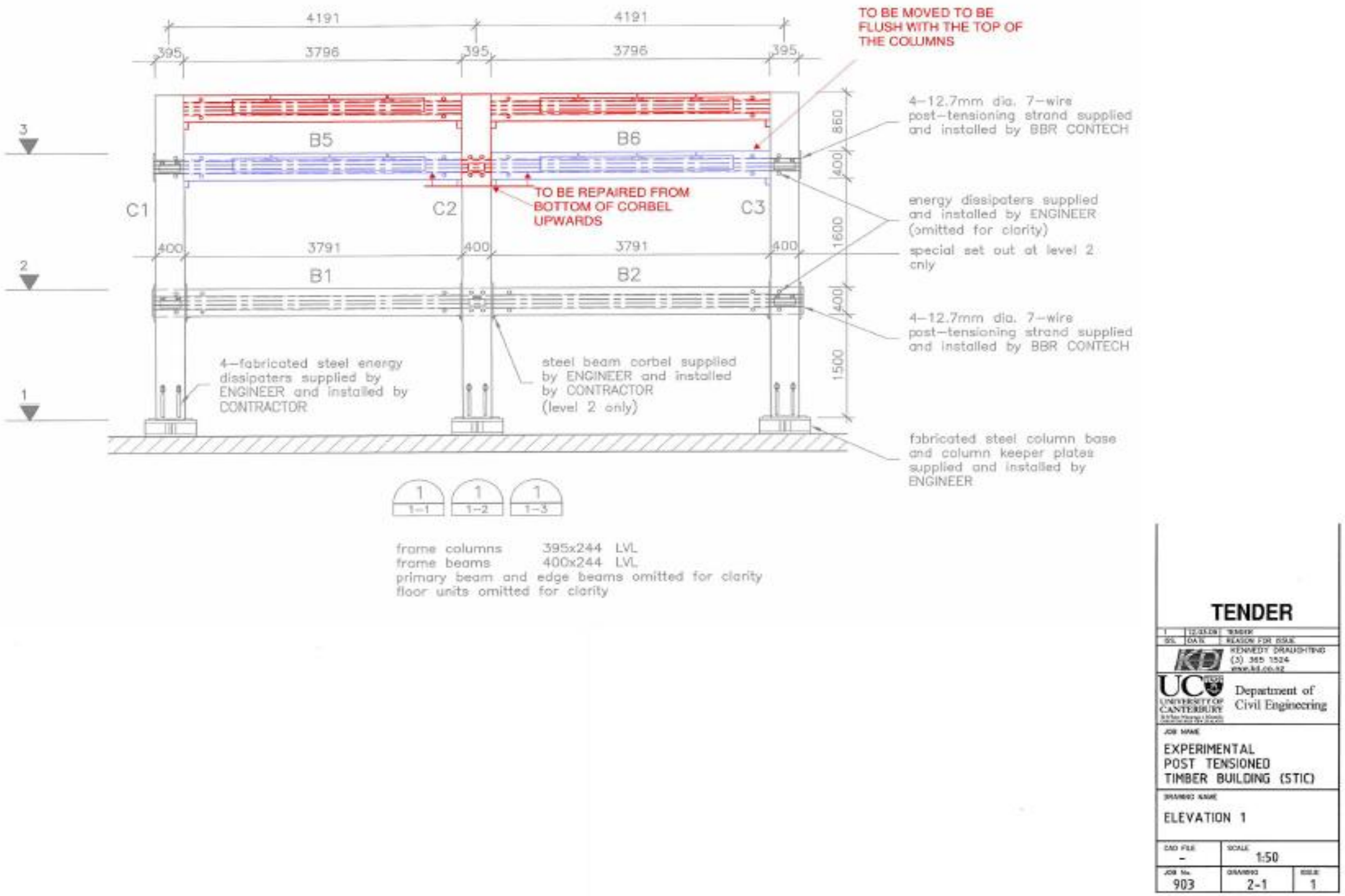
Properties:

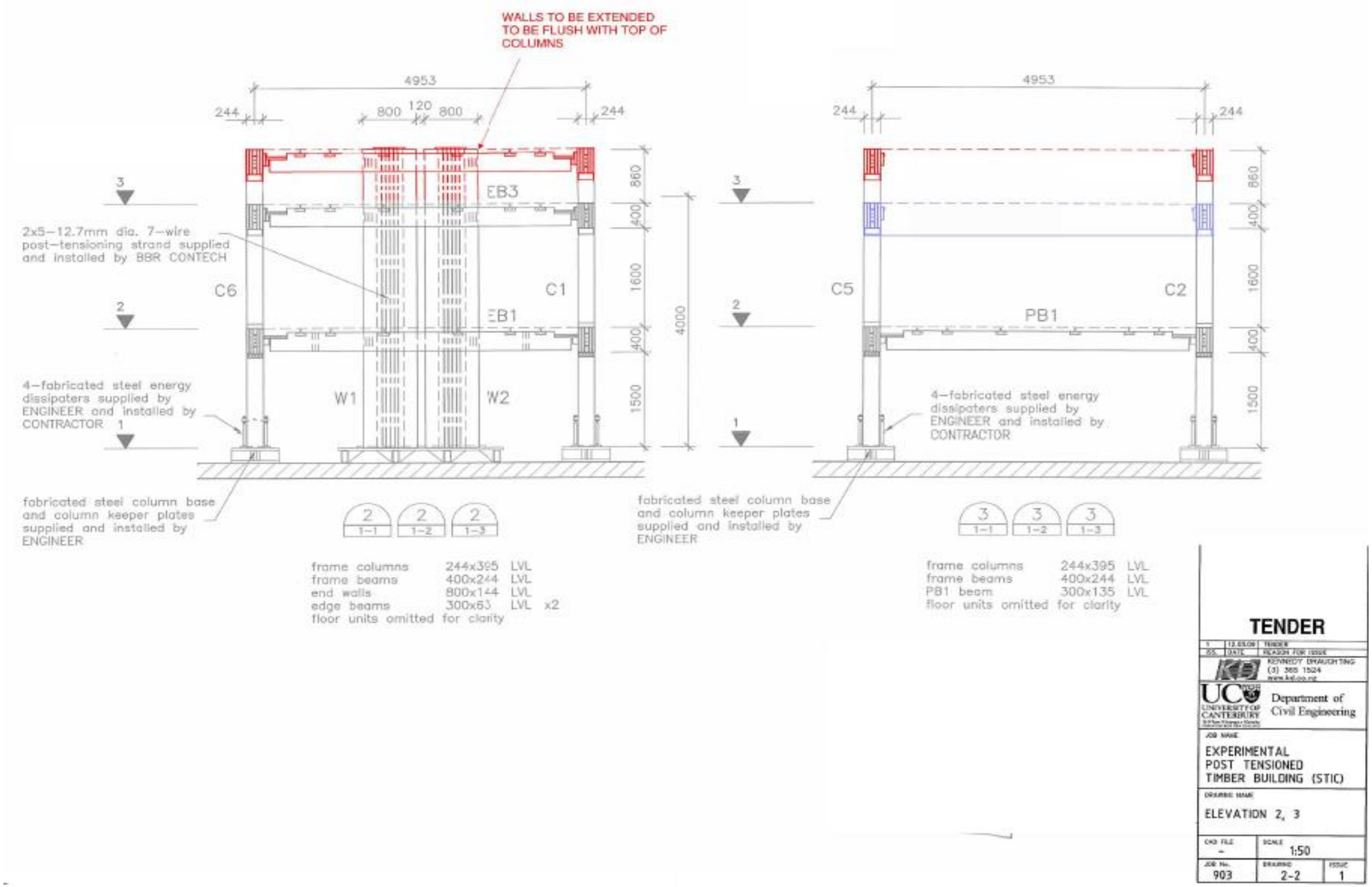
Screw:			
Diameter	d	20	mm
Ult. Stress	fu	880	Mpa
Timber:			
Density	ρ	600	kg/m3
Thickness	t1	350	mm
Thickness	t2	350	mm
		(assume both layers are same density)	

Products:

Charateristic embedding strength (with predrilled holes):			
	fh	39.36	Mpa
Fastener yield moment:			
	My	637209.0211	Nmm
Charateristic axial withdrawel capacity:			
(Fax,Rk/4)/Johansen Part*100		100	% of Johansen Yield Line Theory Part

Capacity:		**Johansen Part**	**Rope effect**	**Total**	
a) Timber failure in layer 1					
	Fv,Rk	275.52		275.52	kN
b) Timber failure in layer 2					
	Fv,Rk	275.52		275.52	kN
c) Rigid rotation of fastener					
	Fv,Rk	435.6353705	435.6353705	871.2707	kN
d) Single hinge 1					
	Fv,Rk	169.218084	169.218084	338.4362	kN
e) Single hinge 2					
	Fv,Rk	169.218084	169.218084	338.4362	kN
f) Double hinge					
	Fv,Rk	36.42472979	36.42472979	72.84946	kN
	Fv,Rk	**36.42472979**		**72.84946**	**kN**


4191
4191
395
3796
395
3796
395
TO BE MOVED TO BE FLUSH WITH THE TOP OF THE COLUMNS
4-12.7mm dia. 7-wire post-tensioning strand supplied and installed by BBR CONTECH
860
400
B5
B6
3
TO BE REPAIRED FROM BOTTOM OF CORBEL UPWARDS
C1
C2
C3
energy dissipaters supplied and installed by ENGINEER (omitted for clarity)
1600
special set out at level 2 only
400
3791
400
3791
400
2
B1
B2
400
4-12.7mm dia. 7-wire post-tensioning strand supplied and installed by BBR CONTECH
4-fabricated steel energy dissipaters supplied by ENGINEER and installed by CONTRACTOR
steel beam corbel supplied by ENGINEER and installed by CONTRACTOR (level 2 only)
1500
1
fabricated steel column base and column keeper plates supplied and installed by ENGINEER
1 1-1
1 1-2
1 1-3
frame columns 395x244 LVL
frame beams 400x244 LVL
primary beam and edge beams omitted for clarity
floor units omitted for clarity
TENDER
KENNEDY DRAUGHTING
Department of Civil Engineering
UNIVERSITY OF CANTERBURY
JOB NAME
EXPERIMENTAL POST TENSIONED TIMBER BUILDING (STIC)
DRAWING NAME
ELEVATION 1
CAD FILE
-
SCALE
1:50
JOB No.
903
DRAWING
2-1
ISSUE
1


WALLS TO BE EXTENDED TO BE FLUSH WITH TOP OF COLUMNS
4953
244
800
120
800
244
EB3
EB1
PB1
C6
C1
C5
C2
W1
W2
860
400
1600
1500
4000
2x5–12.7mm dia. 7–wire post–tensioning strand supplied and installed by BBR CONTECH
4–fabricated steel energy dissipaters supplied by ENGINEER and installed by CONTRACTOR
fabricated steel column base and column keeper plates supplied and installed by ENGINEER
frame columns 244x395 LVL
frame beams 400x244 LVL
end walls 800x144 LVL
edge beams 300x63 LVL x2
floor units omitted for clarity
PB1 beam 300x135 LVL
TENDER
KENNEDY DRAUGHTING
Department of Civil Engineering
EXPERIMENTAL POST TENSIONED TIMBER BUILDING (STIC)
ELEVATION 2, 3
1:50
903
2-2
1

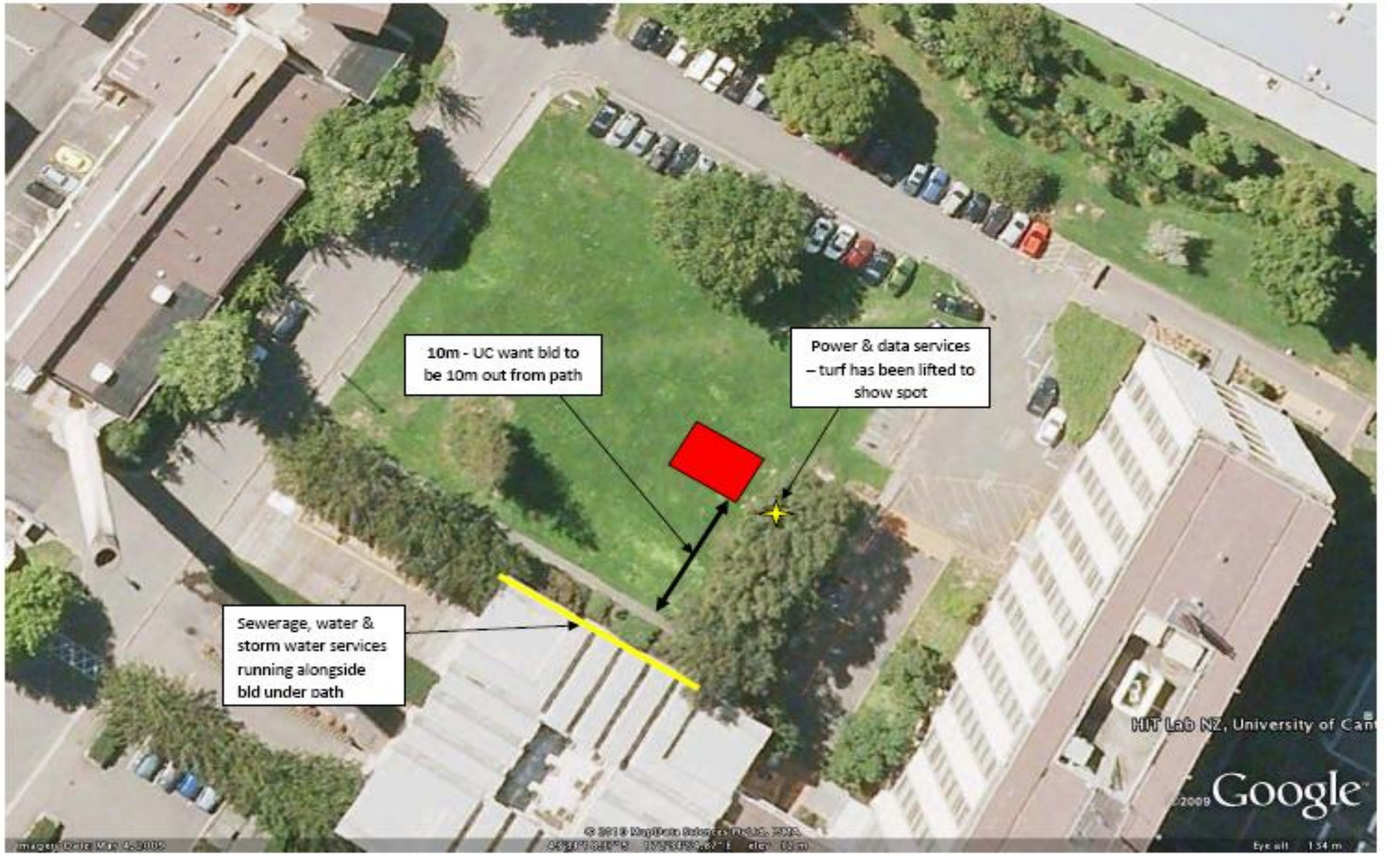
Appendix 15: Deconstruction Time Lapse video for the STIC Experimental two storey Building

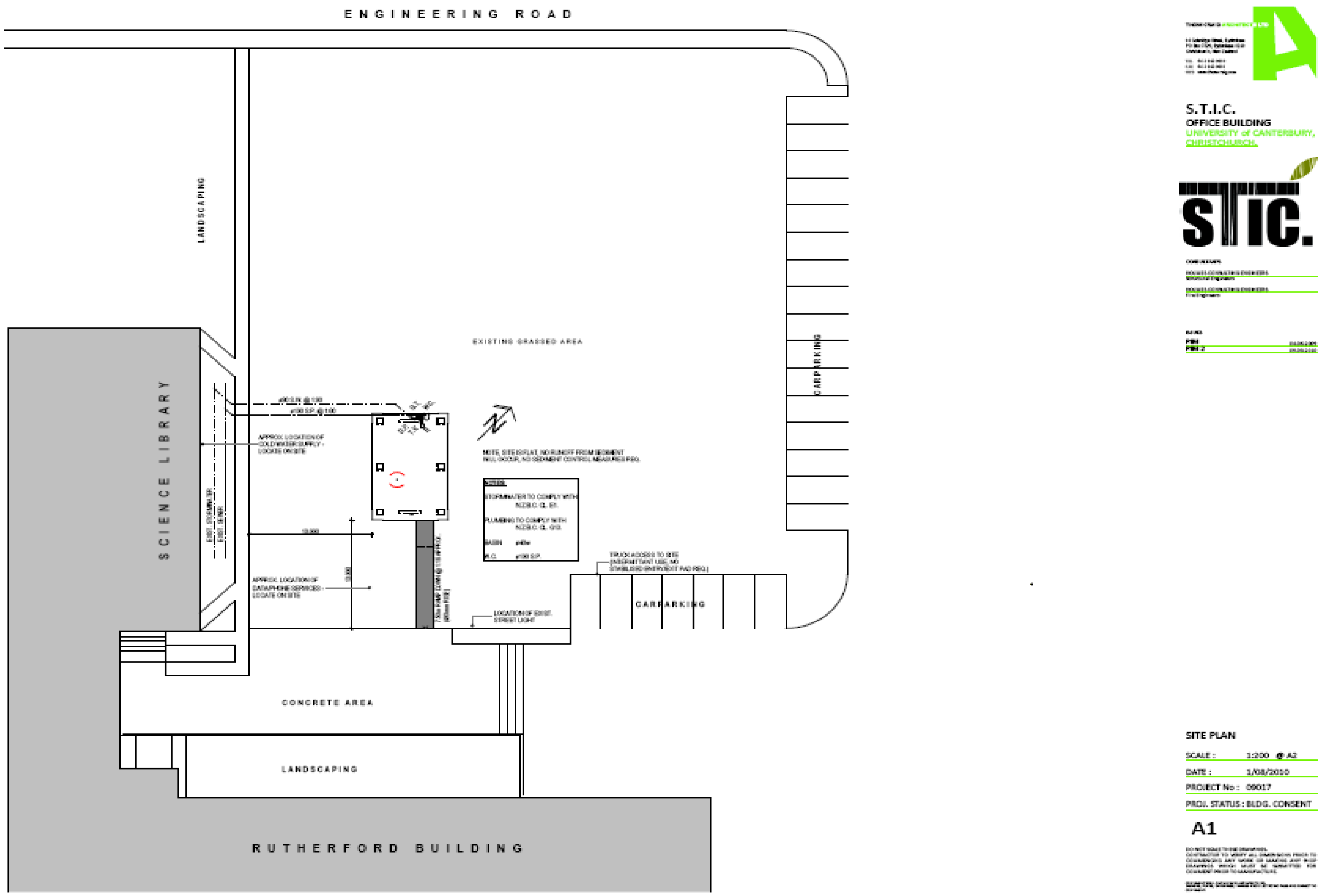
A time lapse deconstruction video for this building has been produced. To view this video pleases goes to “Ctrl + click to the following link”:

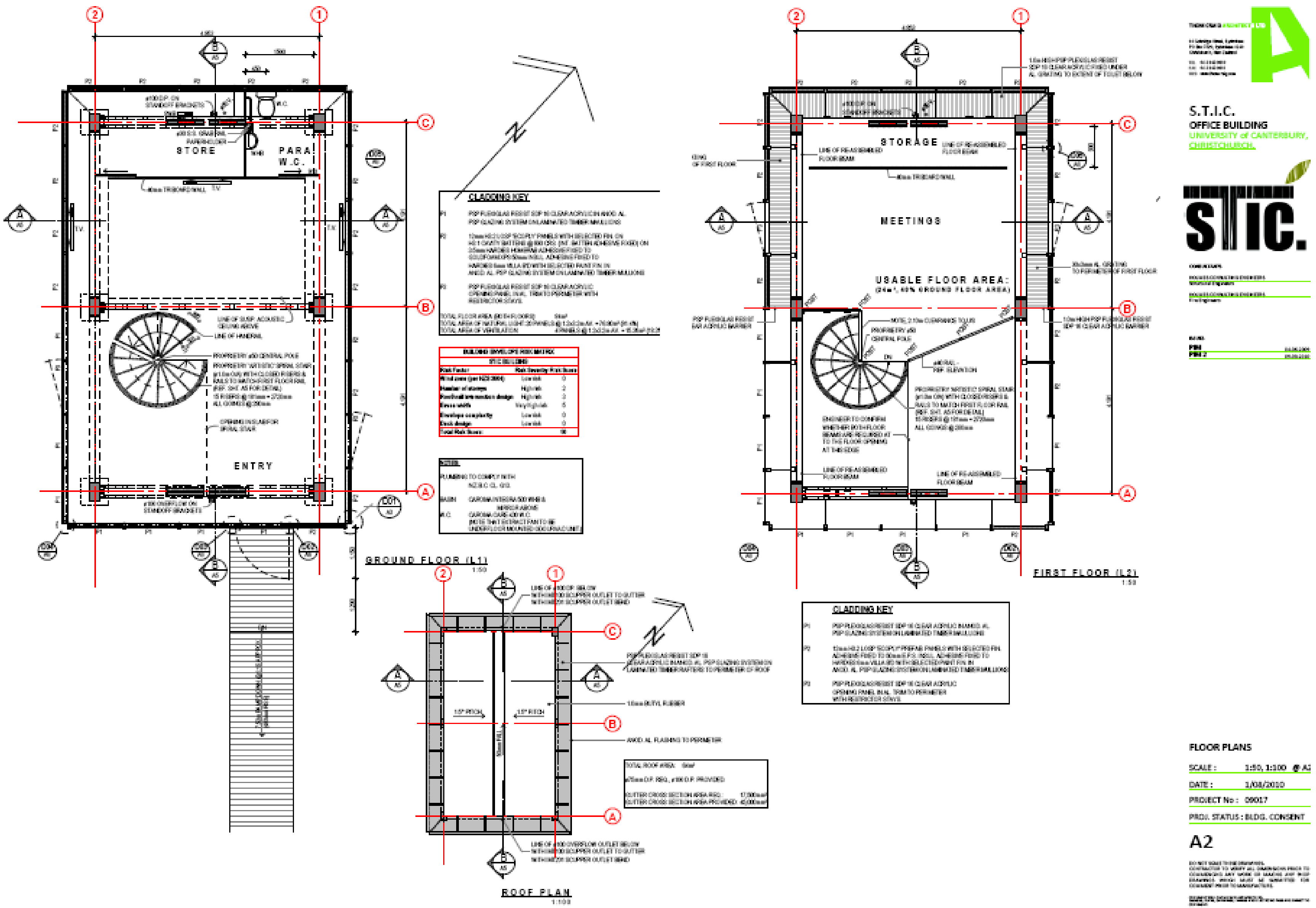
http://www.youtube.com/watch?v=nITAtgEo3R0

Appendix 16: Architectural Drawings for the New of STIC Office Building

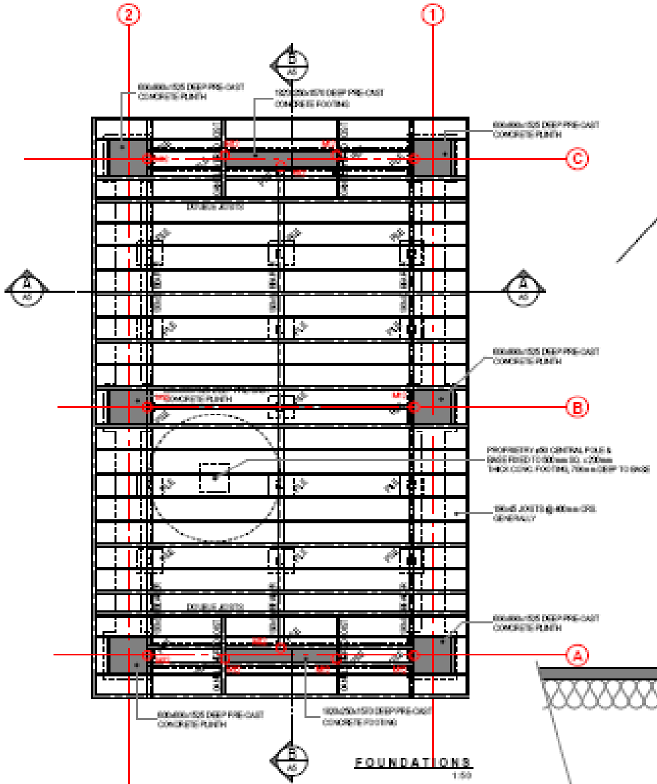
Courtesy from STIC Ltd. and Thom Craig Architects




ENGINEERING ROAD
LANDSCAPING
SCIENCE LIBRARY
EXISTING GRASSED AREA
CARPARKING
APPROX. LOCATION OF COLD WATER SUPPLY - LOCATE ON SITE
APPROX. LOCATION OF DATA/PHONE SERVICES - LOCATE ON SITE
LOCATION OF EXIST. STREET LIGHT
CONCRETE AREA
LANDSCAPING
RUTHERFORD BUILDING
S.T.I.C.
OFFICE BUILDING
UNIVERSITY of CANTERBURY,
CHRISTCHURCH.
STIC.
SITE PLAN
SCALE : 1:200 @ A2
DATE : 1/08/2010
PROJECT No : 09017
PROJ. STATUS : BLDG. CONSENT
A1



STORE
PARA W.C.
ENTRY
GROUND FLOOR (L1)
1:50
CLADDING KEY
BUILDING ENVELOPE RISK MATRIX
STORAGE
MEETINGS
USABLE FLOOR AREA:
FIRST FLOOR (L2)
1:50
CLADDING KEY
ROOF PLAN
1:100
S.T.I.C.
OFFICE BUILDING
UNIVERSITY of CANTERBURY, CHRISTCHURCH.
STIC.
FLOOR PLANS
SCALE : 1:50, 1:100 @ A2
DATE : 1/08/2010
PROJECT No : 09017
PROJ. STATUS : BLDG. CONSENT
A2



FOUNDATIONS
1:50

FOUNDATION NOTES:

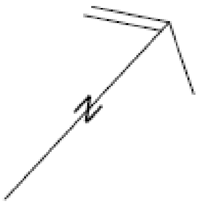
REF. ENG. DWGS. FOR FURTHER INFO.

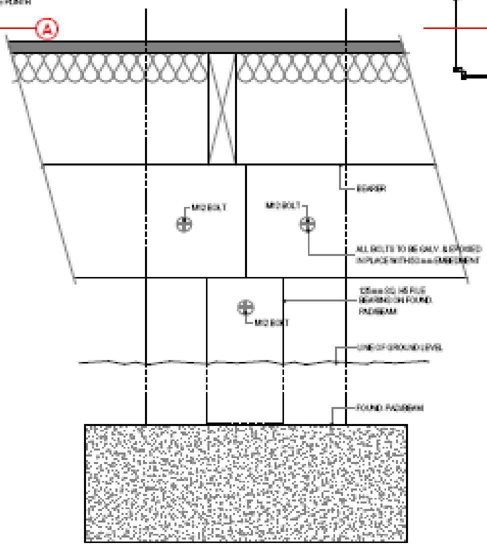
ALL JOISTS TO BE 190x45 @ 400 CRS., H1.2 TREATED

BEARERS TO BE 190x90, H1.2 TREATED, FIXED TO PILES WITH 2/4.0mm WIRE DOGS & 2/100x3.75mm NAILS

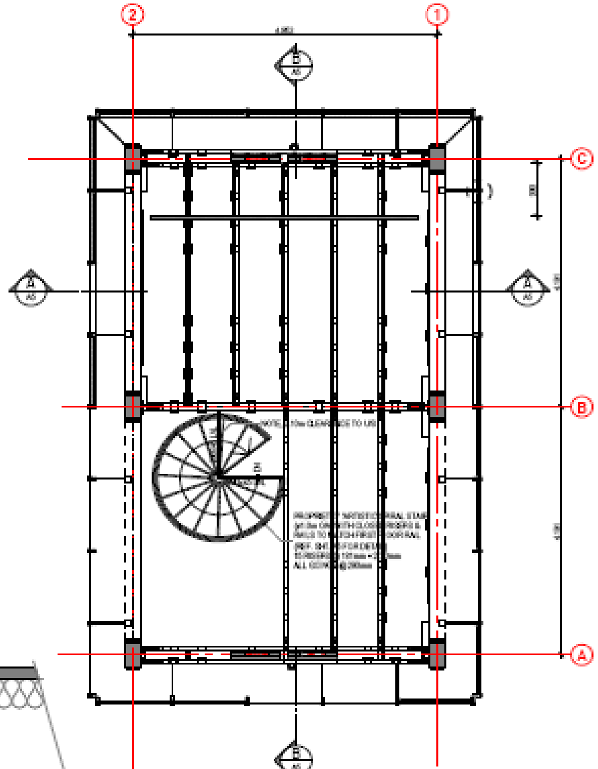
PILES TO BE 125mm SQ., H5 TREATED & EMBEDDED 100mm INTO 400mm SQ. x200mm THICK CONC. FOOTINGS

M12 – REF. TO DETAIL ON THIS SHEET FOR FIXING OF FLOOR FRAMING TO CONC. FOUNDATIONS





TYPICAL SUB-FLOOR FIXING DETAIL



FIRST FLOOR FRAMING PLAN
1:50

S.T.I.C.
OFFICE BUILDING
UNIVERSITY of CANTERBURY, CHRISTCHURCH.

STIC.

FRAMING PLANS

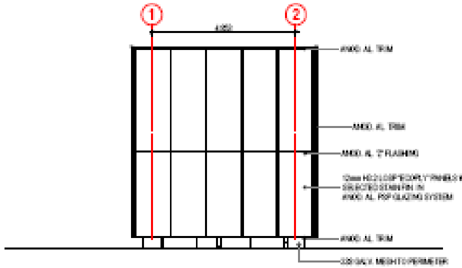
SCALE : 1:50, 1:5 @ A2

DATE : 1/08/2010

PROJECT No : 09017

PROJ. STATUS : BLDG. CONSENT

A3



NORTHWEST ELEVATION
SCALE 1:100
NOTE, UNLESS OTHERWISE INDICATED, ALL PANELS ARE 12mm H3.2 LOSP 'ECOPLY' PANELS WITH SELECTED STAIN FIN IN ANOD. AL. PSP GLAZING SYSTEM

CLADDING KEY

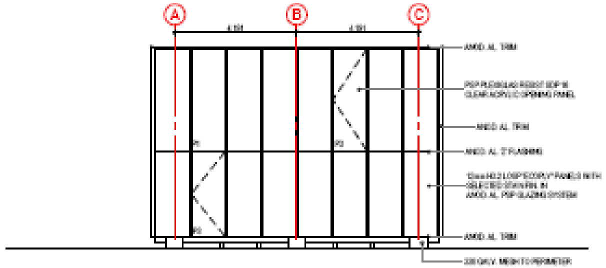
P1 PSP PLEXIGLAS RESIST SDP 16 CLEAR ACRYLIC IN ANOD. AL. PSP GLAZING SYSTEM ON LAMINATED TIMBER MULLIONS

P2 12mm H3.2 LOSP 'ECOPLY' PANELS WITH SELECTED FIN. ON H3.1 CAVITY BATTENS @ 600 CRS. (INT. BATTEN ADHESIVE FIXED) ON 3.5mm HARDIES HOMERAB ADHESIVE FIXED TO GOLDFOAM EPS 50mm INSUL. ADHESIVE FIXED TO HARDIES 6mm VILLABOARD WITH SELECTED PAINT FIN. IN ANOD. AL. PSP GLAZING SYSTEM ON LAMINATED TIMBER MULLIONS

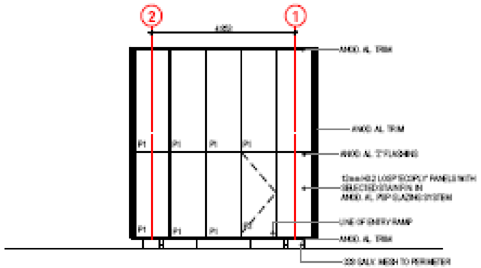
P3 PSP PLEXIGLAS RESIST SDP 16 CLEAR ACRYLIC OPENING PANEL IN AL. TRIM TO PERIMETER WITH RESTRICTOR STAYS.

NOTE: ALL OPENING PANELS, INCLUDING DOOR TO HAVE S/S HINGES & 3 POINT FIXING TO OPPOSITE EDGES.

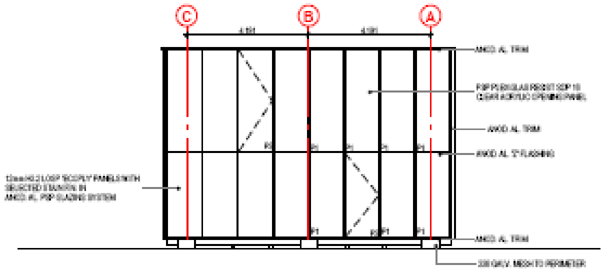
LIAISE WITH UNIVERSITY OF CANTERBURY FACILITIES MANAGEMENT FOR KEYING OF LOCKING ETC.



NORTHEAST ELEVATION
SCALE 1:100
NOTE, UNLESS OTHERWISE INDICATED, ALL PANELS ARE 12mm H3.2 LOSP 'ECOPLY' PANELS WITH SELECTED STAIN FIN. IN ANOD. AL. PSP GLAZING SYSTEM



SOUTHEAST (ENTRY) ELEVATION
SCALE 1:100
NOTE, UNLESS OTHERWISE INDICATED, ALL PANELS ARE 12mm H3.2 LOSP 'ECOPLY' PANELS WITH SELECTED STAIN FIN IN ANOD. AL. PSP GLAZING SYSTEM



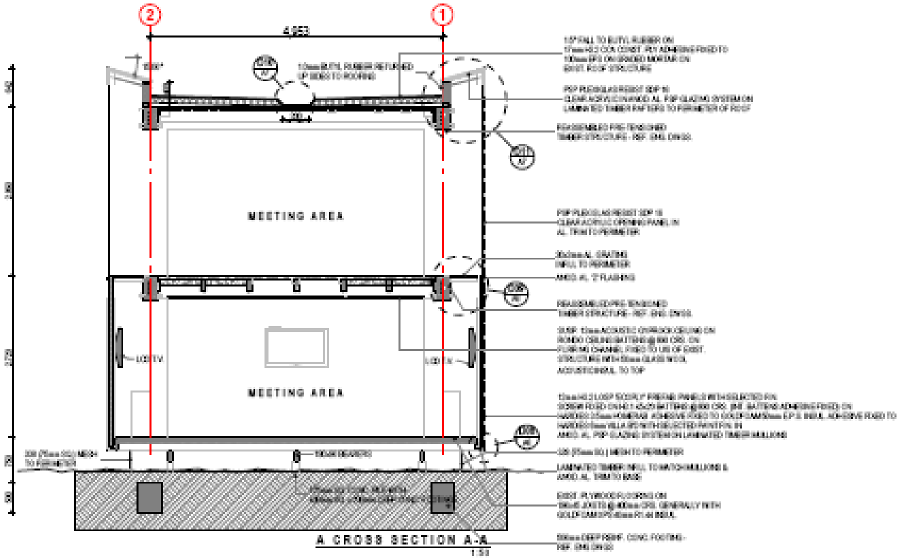
SOUTHWEST ELEVATION
SCALE 1:100
NOTE, UNLESS OTHERWISE INDICATED, ALL PANELS ARE 12mm H3.2 LOSP 'ECOPLY' PANELS WITH SELECTED STAIN FIN IN ANOD. AL. PSP GLAZING SYSTEM

S.T.I.C.
OFFICE BUILDING
UNIVERSITY of CANTERBURY, CHRISTCHURCH.

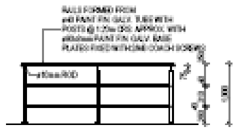
ELEVATIONS

SCALE : 1:100 @ A2
DATE : 1/08/2010
PROJECT No : 09017
PROJ. STATUS : BLDG. CONSENT

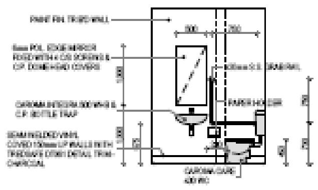
A4



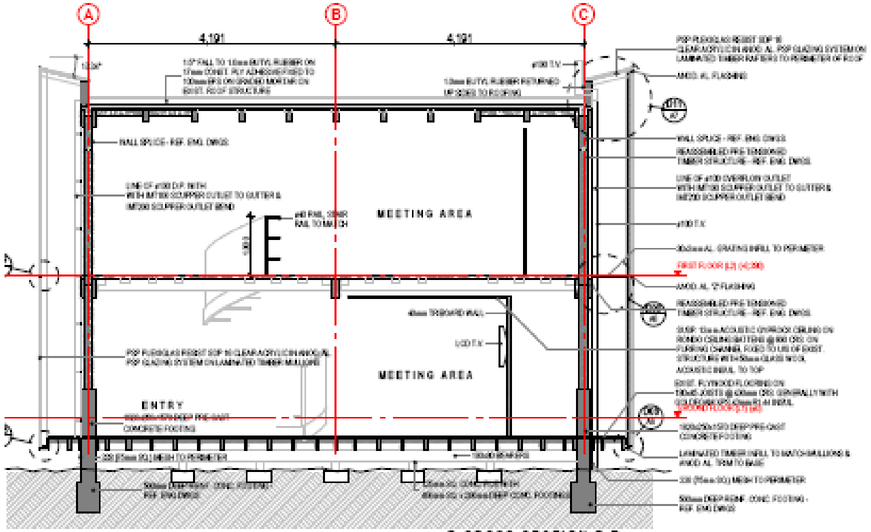
A CROSS SECTION A-A
1:50



RAIL ELEVATION



W.C. INTERIOR ELEVATION



B CROSS SECTION B-B
1:50

S.T.I.C.
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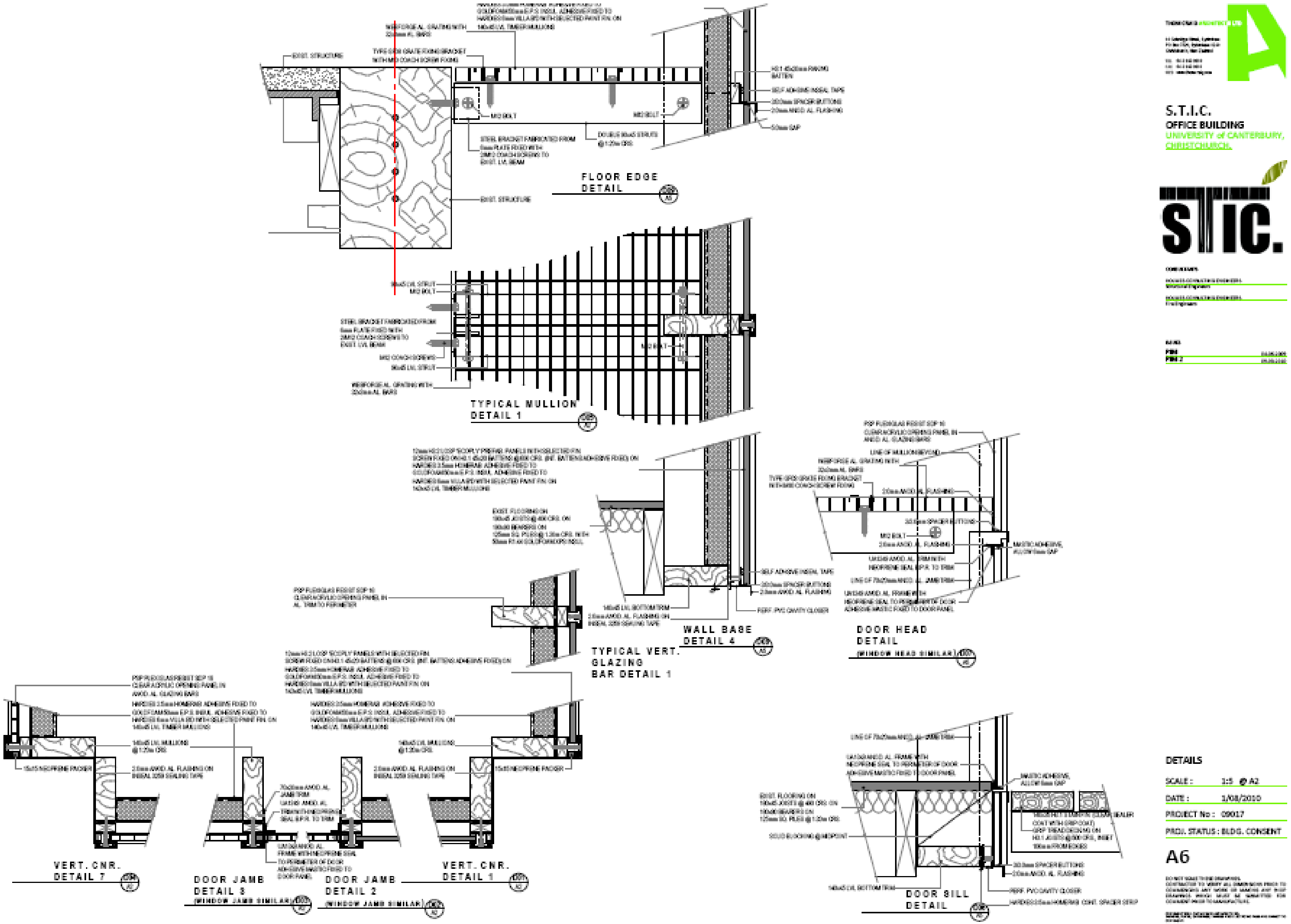
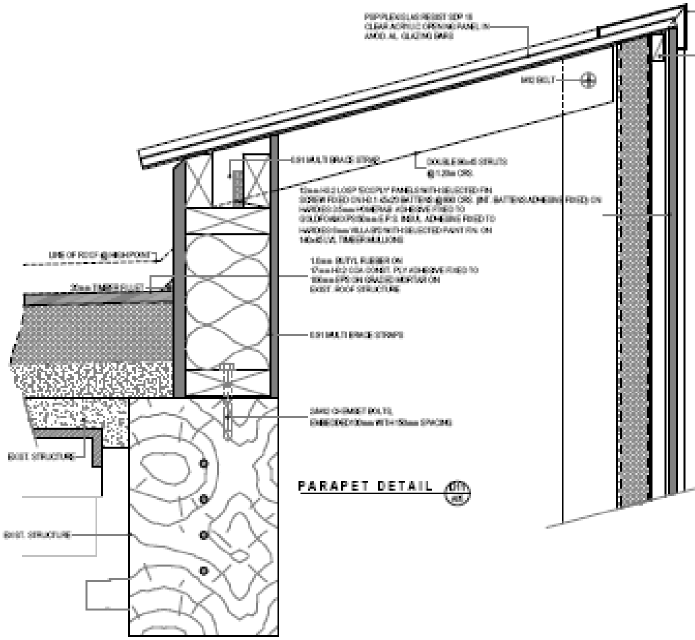
UNIVERSITY of CANTERBURY,
CHRISTCHURCH.

CROSS SECTIONS

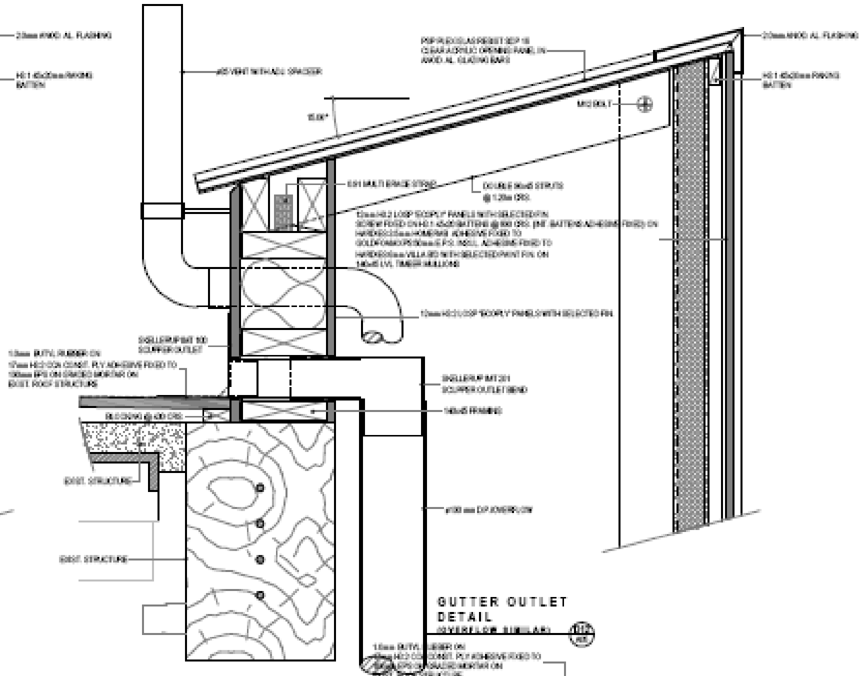
SCALE : 1:50 @ A2
DATE : 1/08/2010
PROJECT No : 09017
PROJ. STATUS : BLDG. CONSENT

A5

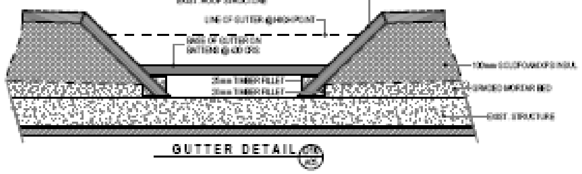

FLOOR EDGE DETAIL
TYPICAL MULLION DETAIL 1
WALL BASE DETAIL 4
TYPICAL VERT. GLAZING BAR DETAIL 1
DOOR HEAD DETAIL
(WINDOW HEAD SIMILAR)
VERT. CNR. DETAIL 7
DOOR JAMB DETAIL 3
(WINDOW JAMB SIMILAR)
DOOR JAMB DETAIL 2
(WINDOW JAMB SIMILAR)
VERT. CNR. DETAIL 1
DOOR SILL DETAIL
S.T.I.C.
OFFICE BUILDING
UNIVERSITY of CANTERBURY,
CHRISTCHURCH.
STIC.
DETAILS
SCALE : 1:5 @ A2
DATE : 1/08/2010
PROJECT No : 09017
PROJ. STATUS : BLDG. CONSENT
A6



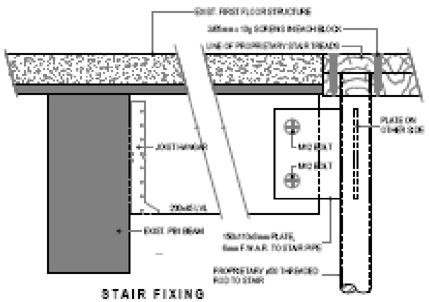
PARAPET DETAIL



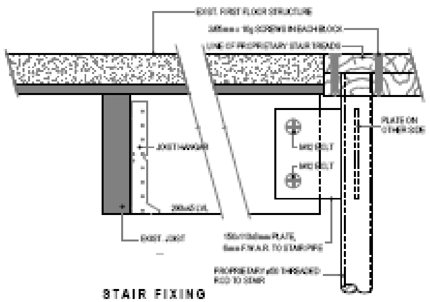
GUTTER OUTLET DETAIL (OVERFLOW SIMILAR)



GUTTER DETAIL



STAIR FIXING DETAIL (IN DIRECTION OF SECTION B-B)



STAIR FIXING DETAIL (IN DIRECTION OF SECTION A-A)

S.T.I.C.

OFFICE BUILDING

UNIVERSITY of CANTERBURY, CHRISTCHURCH.

DETAILS

SCALE : 1:5 @ A2

DATE : 1/08/2010

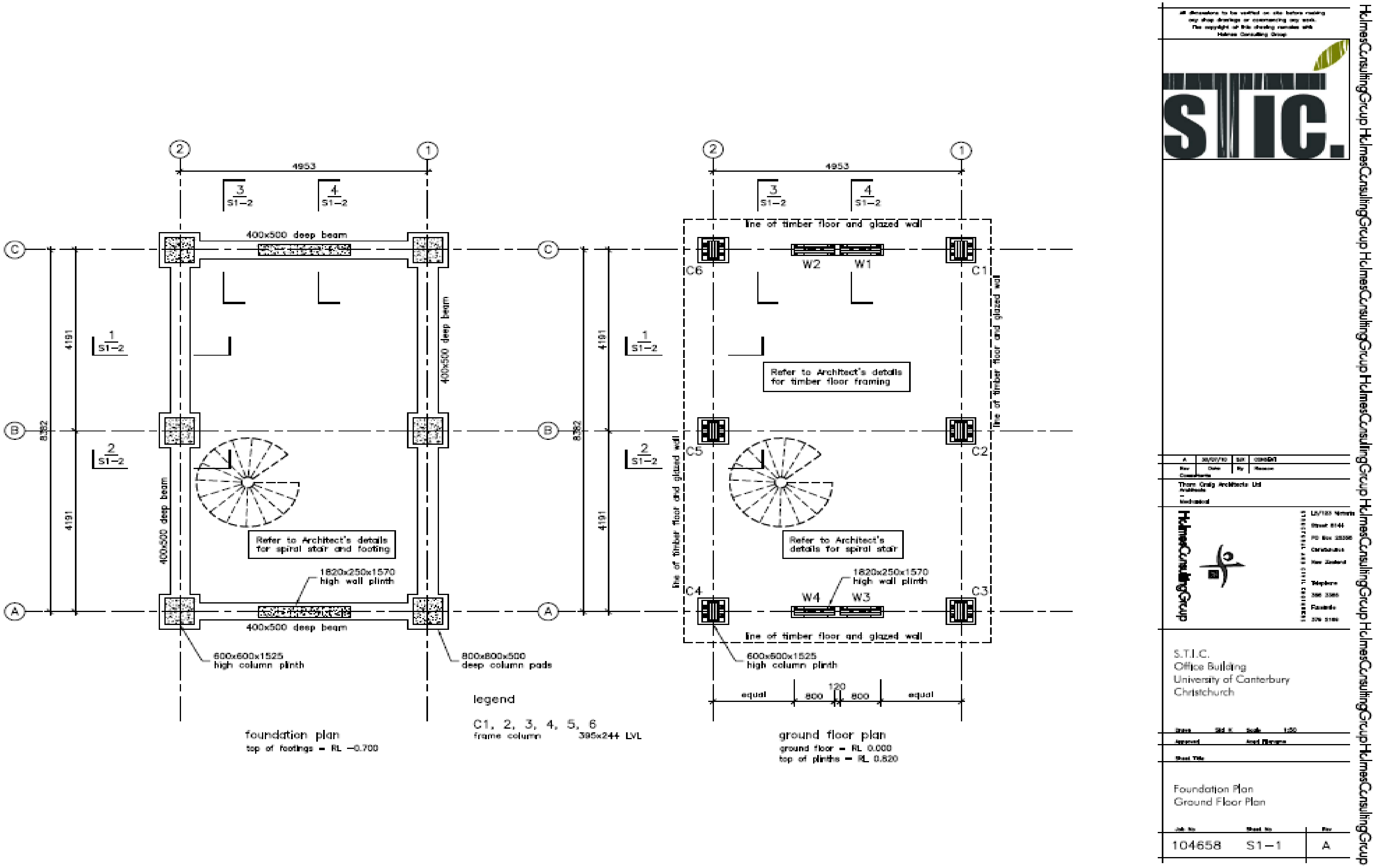
PROJECT No : 09017

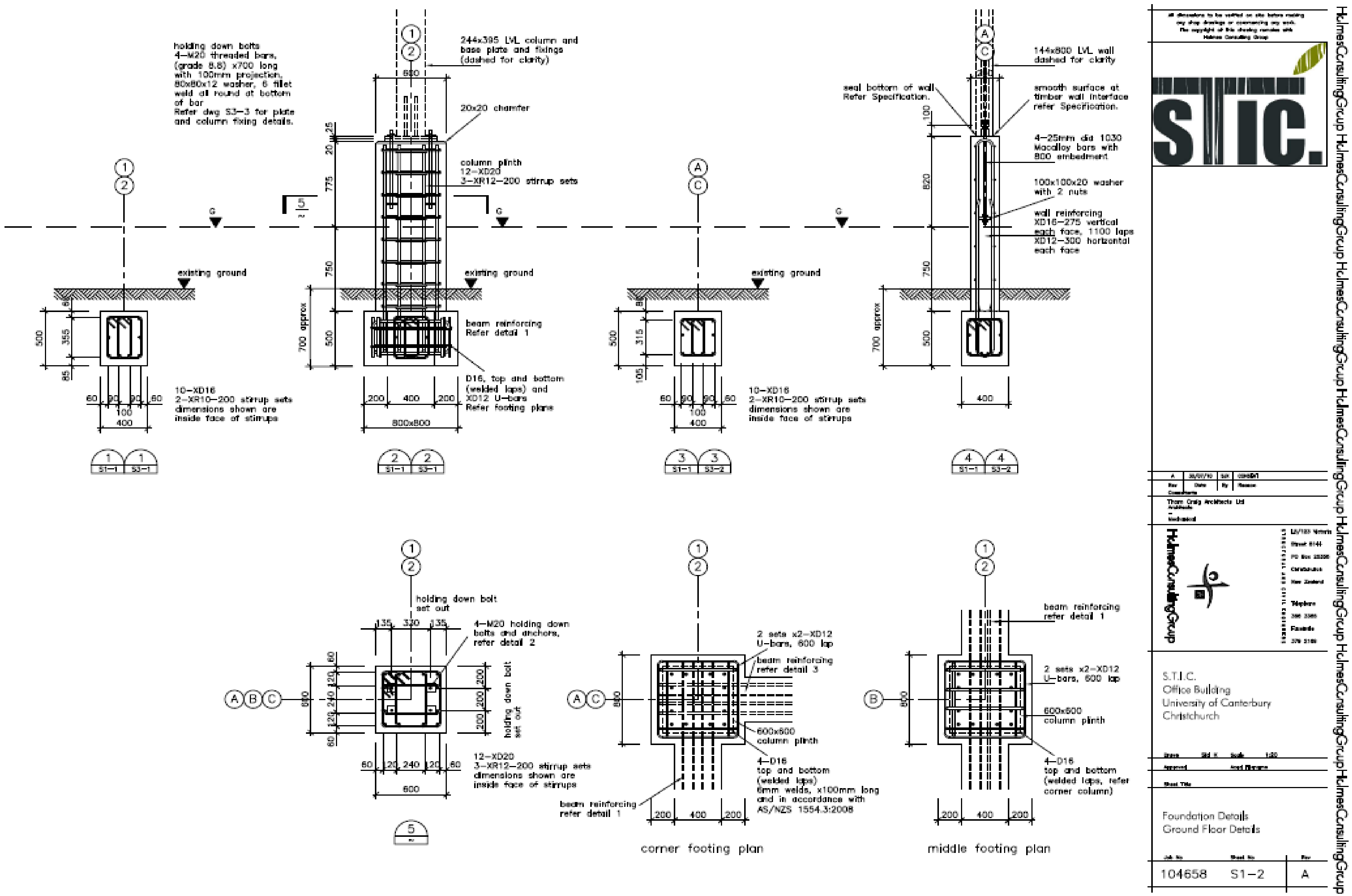
PROJ. STATUS : BLDG. CONSENT

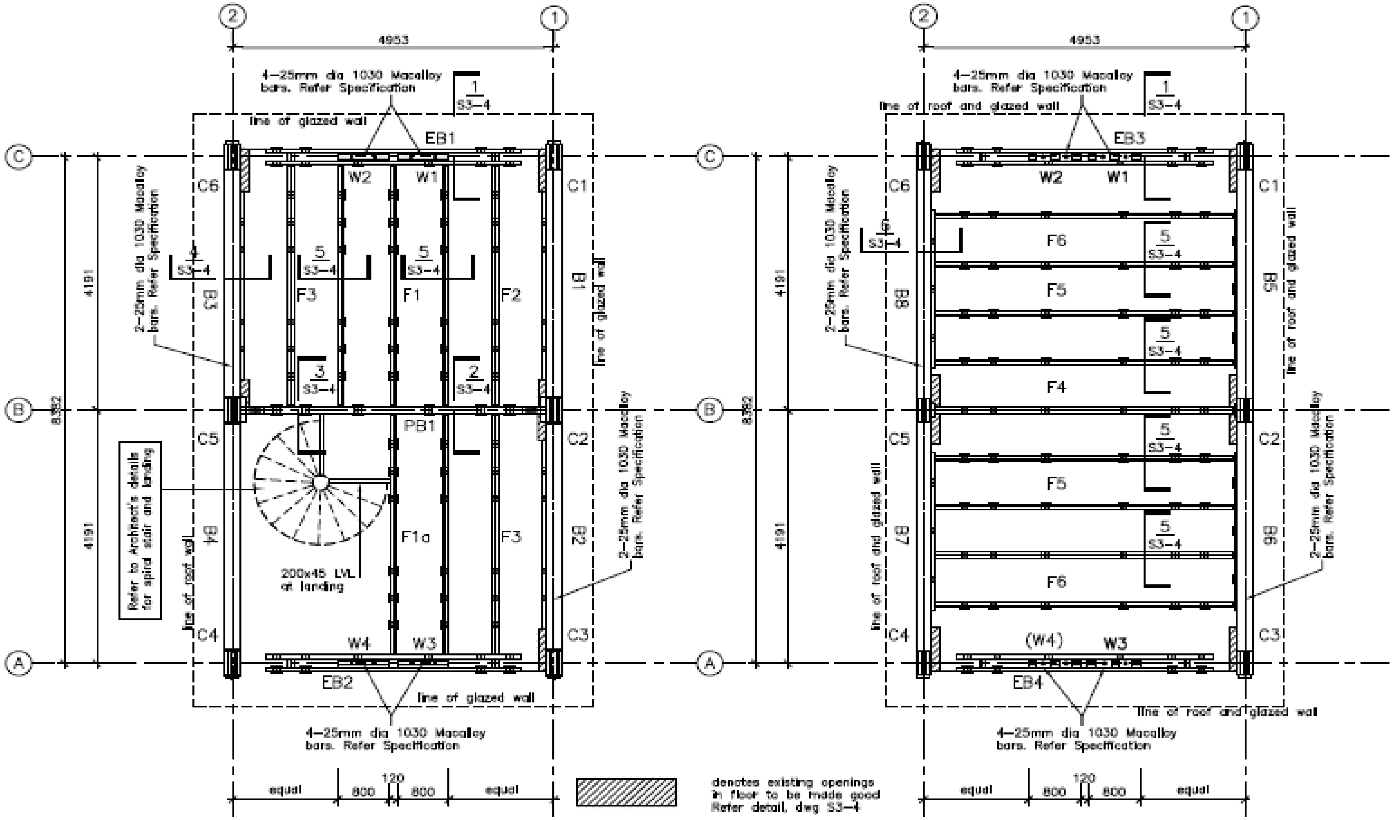
A7

Appendix 17: Engineering Drawings for the New STIC Office Building

Courtesy from STIC Ltd and Holmes Consultancy Group




holding down bolts
4–M20 threaded bars, (grade 8.8) x700 long with 100mm projection, 80x80x12 washer, 6 fillet weld all round at bottom of bar
Refer dwg S3–3 for plate and column fixing details.
244x395 LVL column and base plate and fixings (dashed for clarity)
20x20 chamfer
column plinth
12–XD20
3–XR12–200 stirrup sets
existing ground
beam reinforcing
Refer detail 1
D16, top and bottom (welded laps) and XD12 U–bars
Refer footing plans
10–XD16
2–XR10–200 stirrup sets
dimensions shown are inside face of stirrups
800x800
144x800 LVL wall dashed for clarity
seal bottom of wall
Refer Specification.
smooth surface at timber wall interface refer Specification.
4–25mm dia 1030 Macalloy bars with 800 embedment
100x100x20 washer with 2 nuts
wall reinforcing
XD16–275 vertical each face, 1100 laps
XD12–300 horizontal each face
700 approx
holding down bolt set out
4–M20 holding down bolts and anchors, refer detail 2
12–XD20
3–XR12–200 stirrup sets
dimensions shown are inside face of stirrups
2 sets x2–XD12 U–bars, 600 lap
beam reinforcing refer detail 3
600x600 column plinth
4–D16
top and bottom (welded laps)
6mm welds, x100mm long and in accordance with AS/NZS 1554.3:2008
beam reinforcing refer detail 1
corner footing plan
beam reinforcing refer detail 1
2 sets x2–XD12 U–bars, 600 lap
600x600 column plinth
4–D16
top and bottom (welded laps, refer corner column)
middle footing plan
STIC.
Thom Craig Architects Ltd
HolmesConsultingGroup
S.T.I.C.
Office Building
University of Canterbury
Christchurch
Foundation Details
Ground Floor Details
104658
S1–2
A



first floor plan
top of beams = RL 2.720

roof plan
top of beams = RL +5.580

FLOOR NOTES
All prefabricated floor units to have 15mm ply and 200x45 LVL floor joists.
4 joists per unit at F1,2,3,4,5
3 joists per unit at F6 only

denotes existing openings in floor to be made good
Refer detail, dwg S3-4

legend

B1,2,3,4,5,6,7,8	frame beams	244x400 LVL
C1,2,3,4,5,6	frame column	395x244 LVL
EB1,2,3,4	edge beams	63x300 LVL (x2)
F1,2,3,4,5,6	floor units	as detailed
PB1	primary beam	135x300 LVL
W1,2,3,4	end wall	144x800 LVL

STIC.

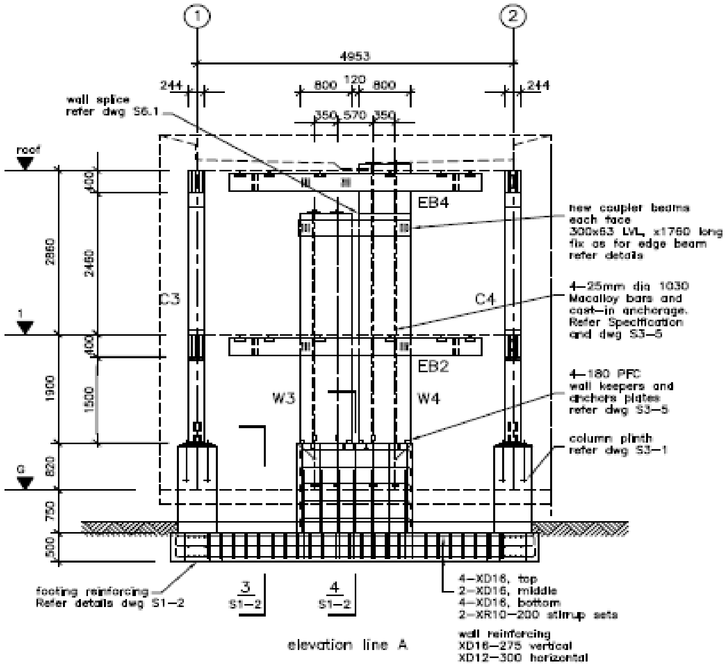
Thorn Craig Architects Ltd

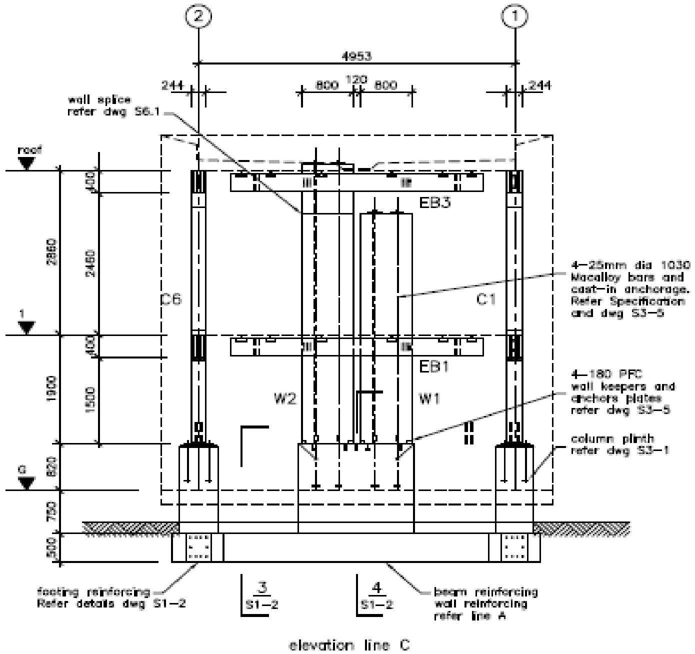
HolmesConsultingGroup

S.T.I.C.
Office Building
University of Canterbury
Christchurch

Sheet Title
First Floor Plan
Roof Plan

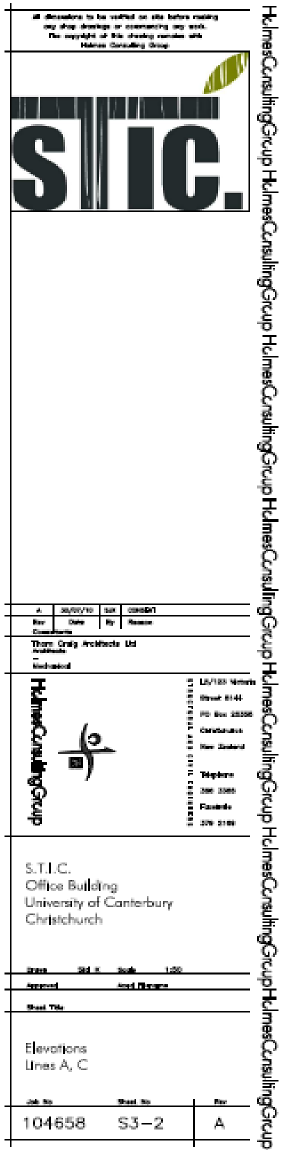
Job No	Sheet No	Rev
104658	S2-1	A

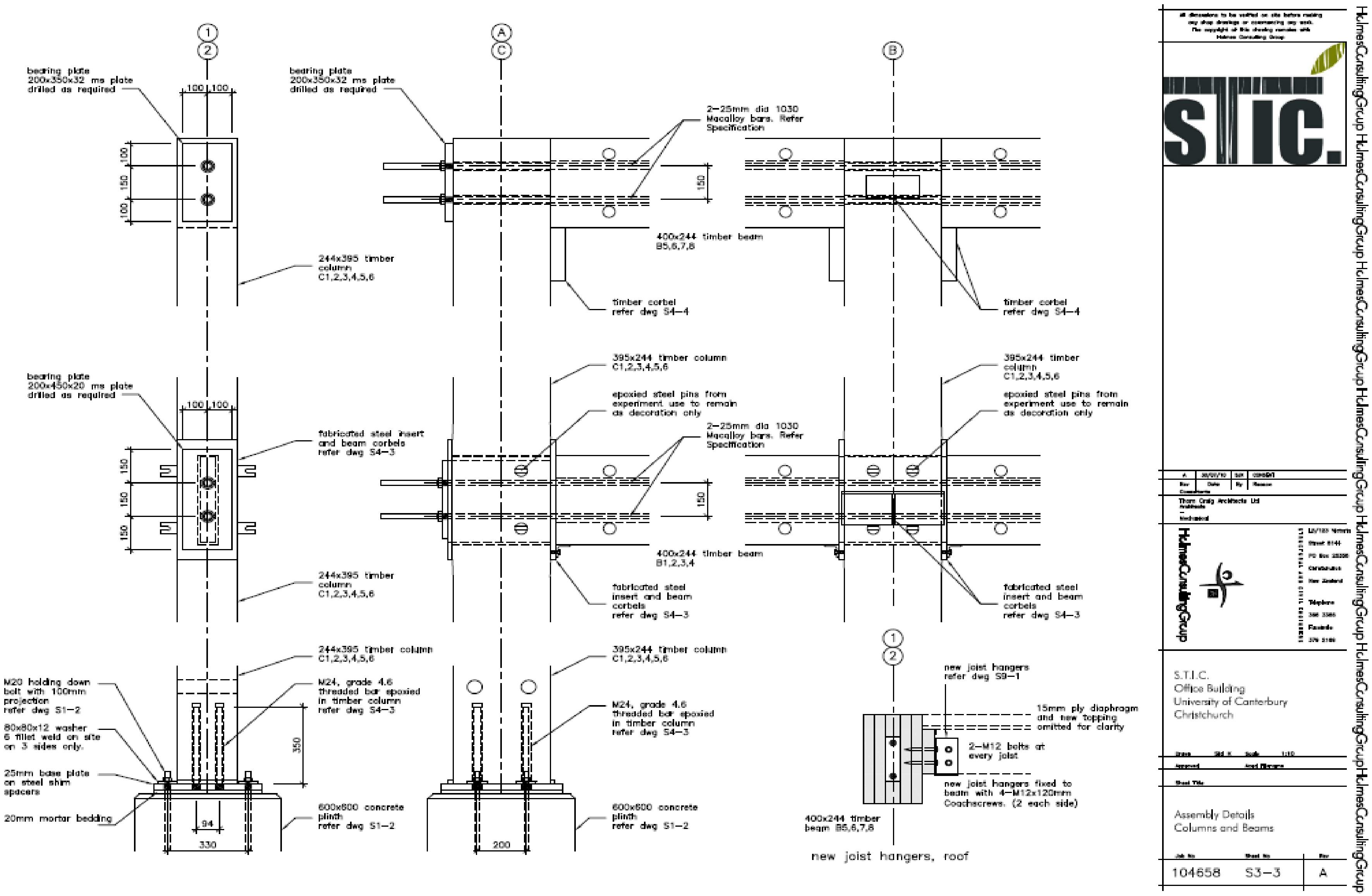




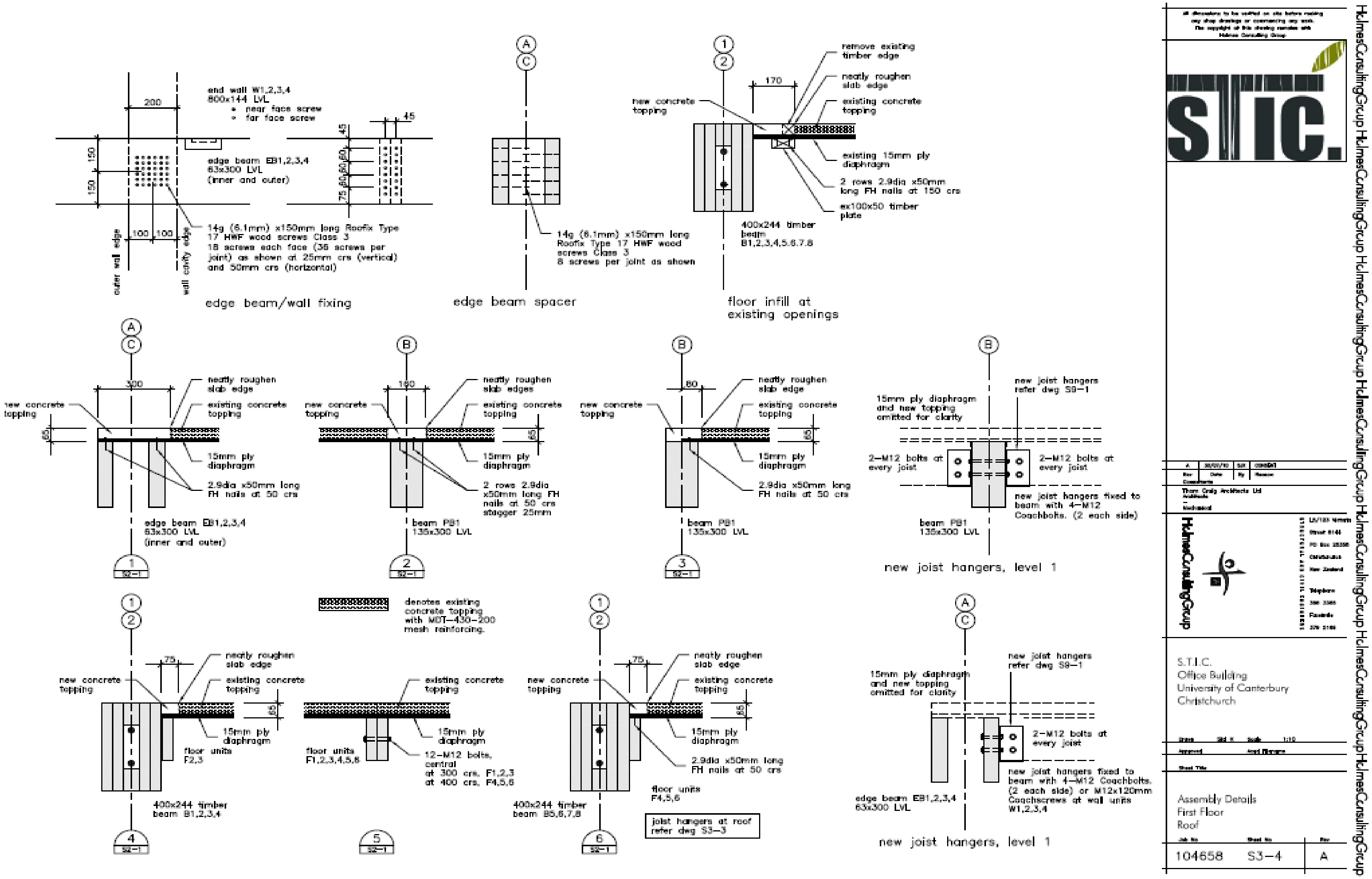
legend

C1,2,3,4,5,6	frame column	395x244 LVL
EB1,2,3,4	edge beams	63x300 LVL (x2)
F1,2,3,4,5,6	floor units	as detailed
W1,2,3,4	end wall	144x800 LVL

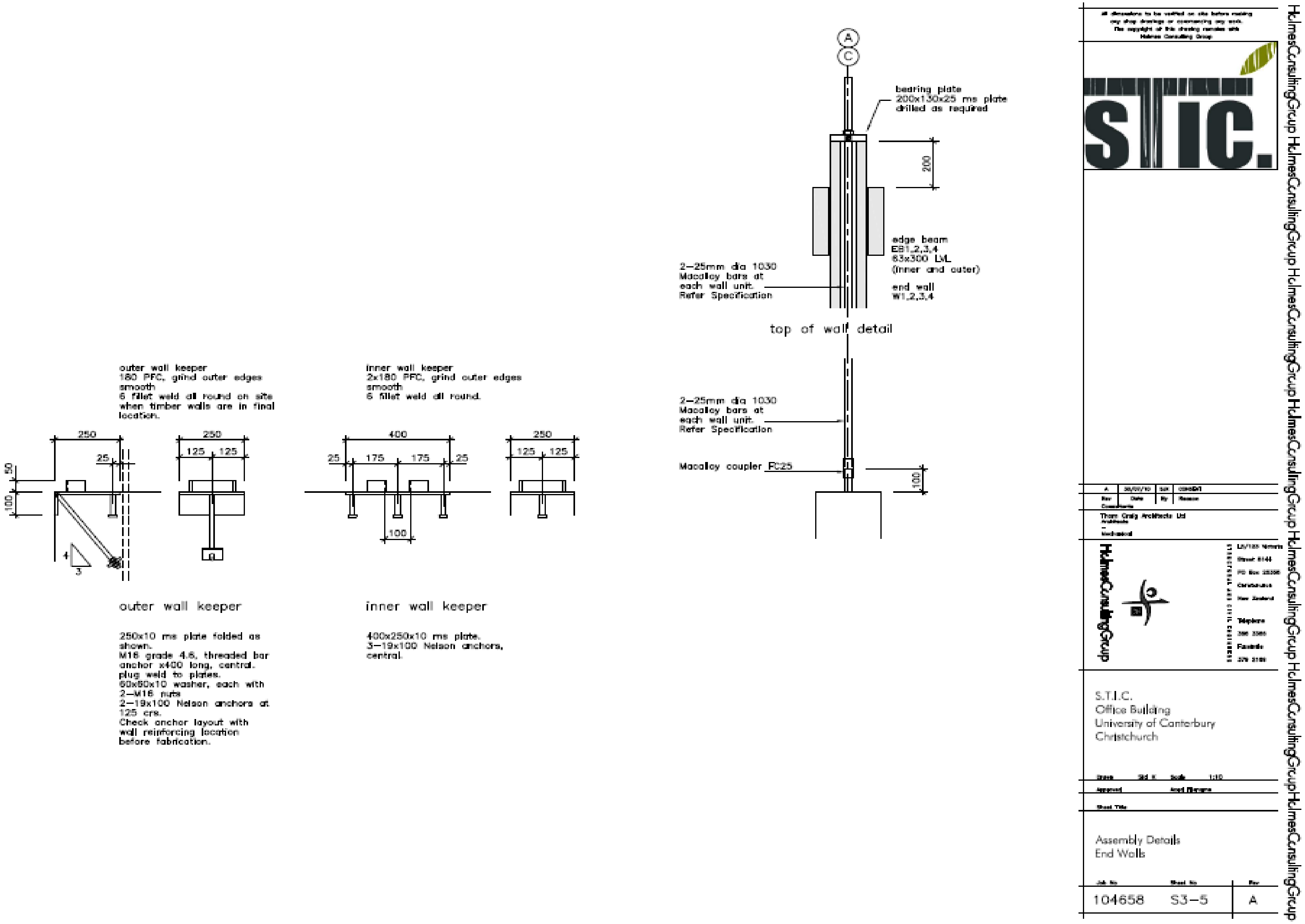


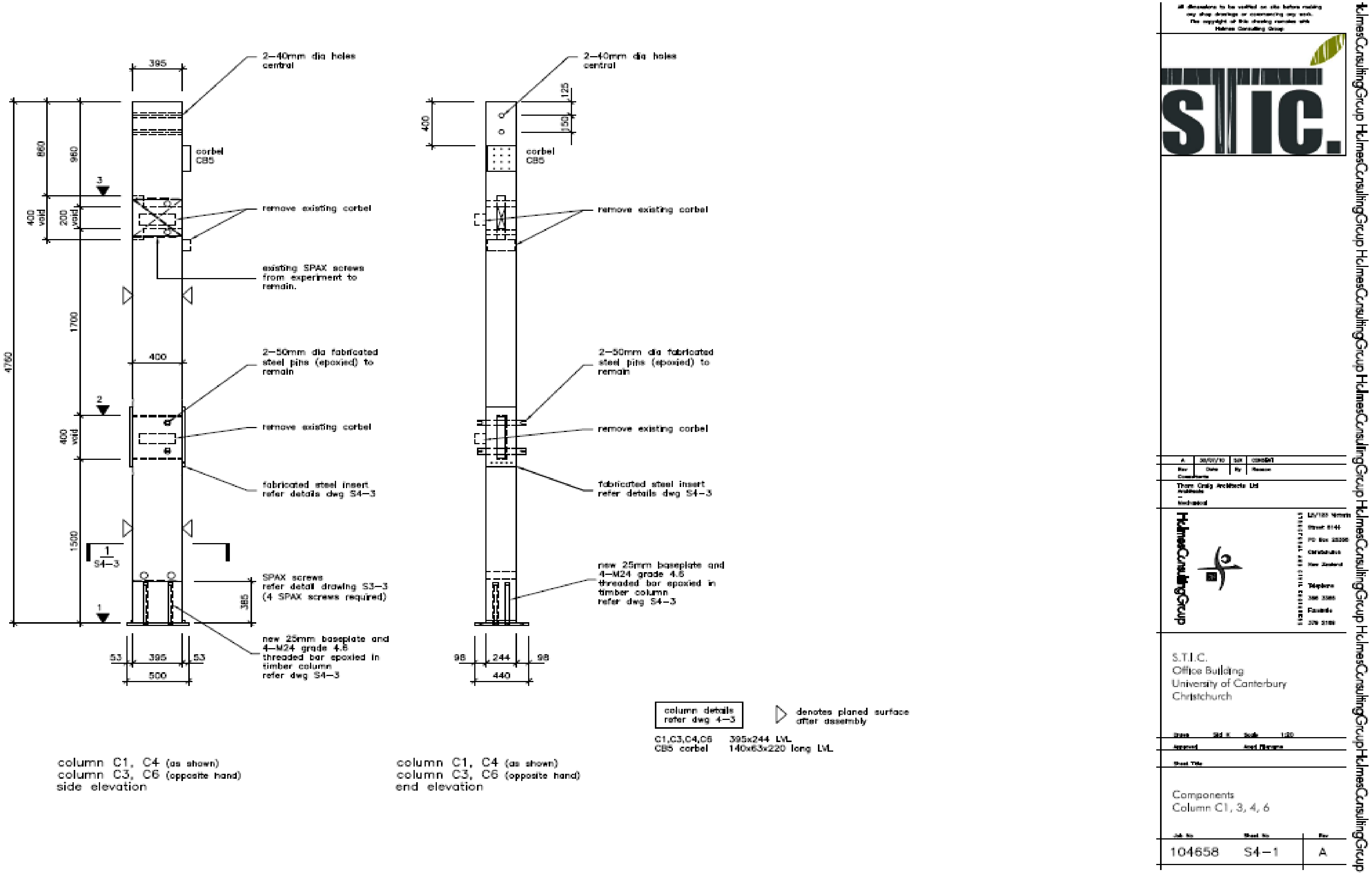


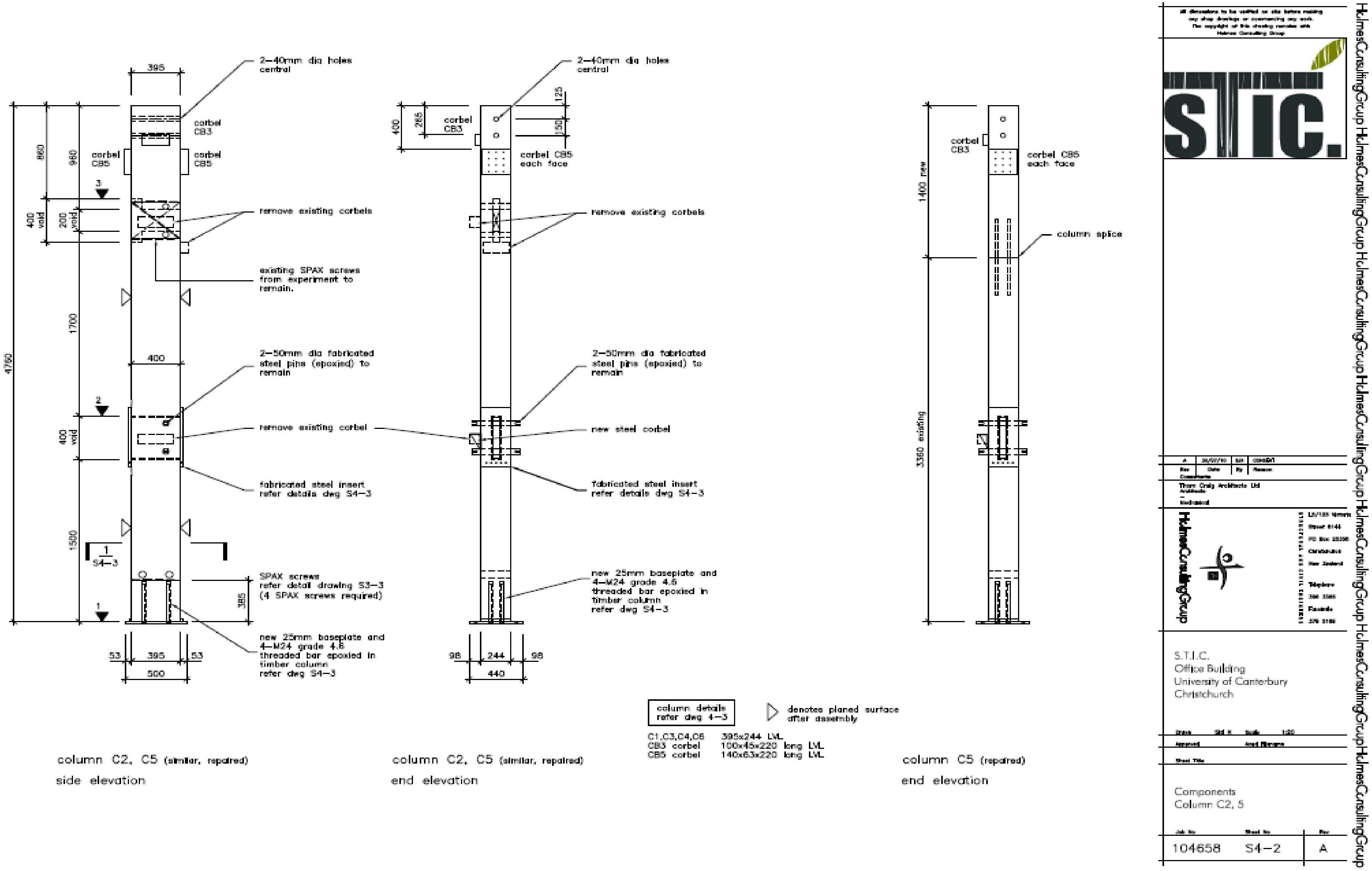
bearing plate 200x350x32 ms plate drilled as required
100 100
244x395 timber column C1,2,3,4,5,6
2–25mm dia 1030 Macalloy bars. Refer Specification
400x244 timber beam B5,6,7,8
timber corbel refer dwg S4–4
bearing plate 200x450x20 ms plate drilled as required
fabricated steel insert and beam corbels refer dwg S4–3
395x244 timber column C1,2,3,4,5,6
epoxied steel pins from experiment use to remain as decoration only
400x244 timber beam B1,2,3,4
fabricated steel insert and beam corbels refer dwg S4–3
244x395 timber column C1,2,3,4,5,6
M20 holding down bolt with 100mm projection refer dwg S1–2
80x80x12 washer 6 fillet weld on site on 3 sides only.
25mm base plate on steel shim spacers
20mm mortar bedding
M24, grade 4.6 threaded bar epoxied in timber column refer dwg S4–3
600x600 concrete plinth refer dwg S1–2
330
200
new joist hangers refer dwg S9–1
15mm ply diaphragm and new topping omitted for clarity
2–M12 bolts at every joist
new joist hangers fixed to beam with 4–M12x120mm Coachscrews. (2 each side)
400x244 timber beam B5,6,7,8
new joist hangers, roof
STIC.
Thom Craig Architects Ltd
HolmesConsultingGroup
S.T.I.C.
Office Building
University of Canterbury
Christchurch
Assembly Details
Columns and Beams
104658
S3–3
A



edge beam/wall fixing
end wall W1,2,3,4
800x144 LVL
near face screw
far face screw
edge beam EB1,2,3,4
63x300 LVL
(inner and outer)
14g (6.1mm) x150mm long Roofix Type 17 HWF wood screws Class 3
18 screws each face (36 screws per joint) as shown at 25mm crs (vertical) and 50mm crs (horizontal)
outer wall edge
wall cavity edge
edge beam spacer
14g (6.1mm) x150mm long Roofix Type 17 HWF wood screws Class 3
8 screws per joint as shown
floor infill at existing openings
new concrete topping
remove existing timber edge
neatly roughen slab edge
existing concrete topping
existing 15mm ply diaphragm
2 rows 2.9dia x50mm long FH nails at 150 crs
ex100x50 timber plate
400x244 timber beam B1,2,3,4,5,6,7,8
15mm ply diaphragm
2.9dia x50mm long FH nails at 50 crs
beam PB1
135x300 LVL
2 rows 2.9dia x50mm long FH nails at 50 crs stagger 25mm
new joist hangers, level 1
new joist hangers refer dwg S9-1
15mm ply diaphragm and new topping omitted for clarity
2-M12 bolts at every joist
new joist hangers fixed to beam with 4-M12 Coachbolts. (2 each side)
denotes existing concrete topping with MDT-430-200 mesh reinforcing.
floor units F2,3
400x244 timber beam B1,2,3,4
floor units F1,2,3,4,5,6
12-M12 bolts, central at 300 crs. F1,2,3 at 400 crs. F4,5,6
floor units F4,5,6
400x244 timber beam B5,6,7,8
joist hangers at roof refer dwg S3-3
new joist hangers fixed to beam with 4-M12 Coachbolts. (2 each side) or M12x120mm Coachscrews at wall units W1,2,3,4
edge beam EB1,2,3,4
63x300 LVL
S.T.I.C.
Office Building
University of Canterbury
Christchurch
Assembly Details
First Floor
Roof
104658
S3-4
A
HolmesConsultingGroup


bearing plate
200x130x25 ms plate
drilled as required
200
edge beam
EB1,2,3,4
63x300 LVL
(inner and outer)
end wall
W1,2,3,4
2–25mm dia 1030
Macalloy bars at
each wall unit.
Refer Specification
top of wall detail
2–25mm dia 1030
Macalloy bars at
each wall unit.
Refer Specification
Macalloy coupler FC25
100
outer wall keeper
180 PFC, grind outer edges
smooth
6 fillet weld all round on site
when timber walls are in final
location.
inner wall keeper
2x180 PFC, grind outer edges
smooth
6 fillet weld all round.
250
25
125
400
175
outer wall keeper
250x10 ms plate folded as
shown.
M16 grade 4.6, threaded bar
anchor x400 long, central.
plug weld to plates.
60x60x10 washer, each with
2–M16 nuts
2–19x100 Nelson anchors at
125 crs.
Check anchor layout with
wall reinforcing location
before fabrication.
inner wall keeper
400x250x10 ms plate.
3–19x100 Nelson anchors,
central.
S.T.I.C.
Office Building
University of Canterbury
Christchurch
Scale 1:10
Assembly Details
End Walls
104658
S3–5
A
HolmesConsultingGroup


2–40mm dia holes central
corbel CB5
remove existing corbel
existing SPAX screws from experiment to remain.
2–50mm dia fabricated steel pins (epoxied) to remain
fabricated steel insert refer details dwg S4–3
SPAX screws refer detail drawing S3–3 (4 SPAX screws required)
new 25mm baseplate and 4–M24 grade 4.6 threaded bar epoxied in timber column refer dwg S4–3
column C1, C4 (as shown)
column C3, C6 (opposite hand)
side elevation
column C1, C4 (as shown)
column C3, C6 (opposite hand)
end elevation
column details refer dwg 4–3
denotes planed surface after assembly
C1,C3,C4,C6 395x244 LVL
CB5 corbel 140x63x220 long LVL
Thom Craig Architects Ltd
HolmesConsultingGroup
S.T.I.C.
Office Building
University of Canterbury
Christchurch
Components
Column C1, 3, 4, 6
104658
S4–1
A


2-40mm dia holes central
corbel CB3
corbel CB5
remove existing corbels
existing SPAX screws from experiment to remain.
2-50mm dia fabricated steel pins (epoxied) to remain
remove existing corbel
fabricated steel insert refer details dwg S4-3
SPAX screws refer detail drawing S3-3 (4 SPAX screws required)
new 25mm baseplate and 4-M24 grade 4.6 threaded bar epoxied in timber column refer dwg S4-3
corbel CB5 each face
new steel corbel
column splice
1400 new
3360 existing
4760
column details refer dwg 4-3
denotes planed surface after assembly
C1,C3,C4,C6 395x244 LVL
CB3 corbel 100x45x220 long LVL
CB5 corbel 140x63x220 long LVL
column C2, C5 (similar, repaired)
side elevation
column C2, C5 (similar, repaired)
end elevation
column C5 (repaired)
end elevation
Thorn Craig Architects Ltd
Holmes Consulting Group
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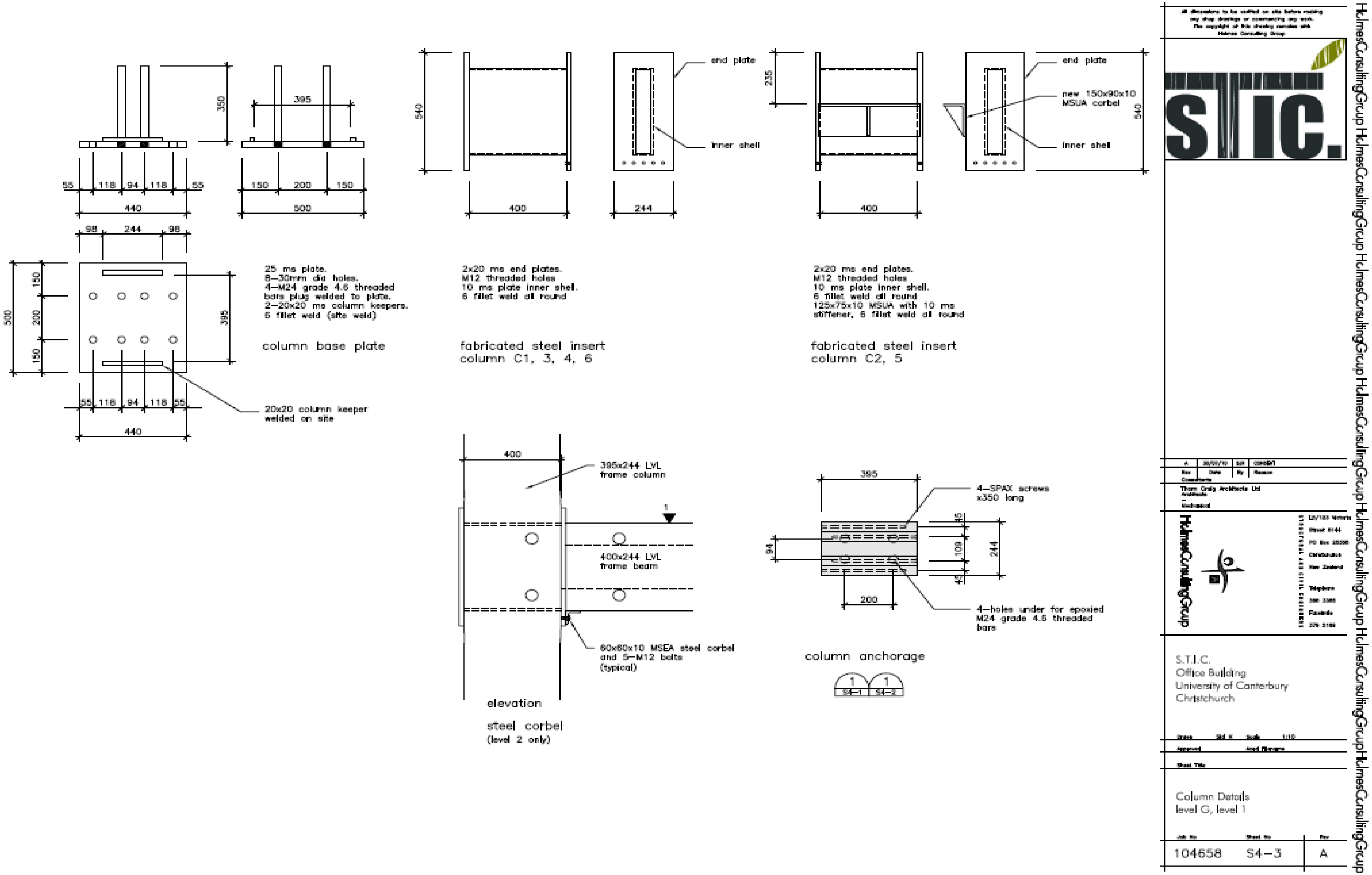
Office Building
University of Canterbury
Christchurch
Components
Column C2, 5
104658
S4-2
A


25 ms plate.
8–30mm dia holes.
4–M24 grade 4.6 threaded bars plug welded to plate.
2–20x20 ms column keepers.
6 fillet weld (site weld)
column base plate
20x20 column keeper welded on site
2x20 ms end plates.
M12 threaded holes
10 ms plate inner shell.
6 fillet weld all round
fabricated steel insert
column C1, 3, 4, 6
end plate
inner shell
2x20 ms end plates.
M12 threaded holes
10 ms plate inner shell.
6 fillet weld all round
125x75x10 MSUA with 10 ms stiffener, 6 fillet weld all round
fabricated steel insert
column C2, 5
new 150x90x10 MSUA corbel
395x244 LVL frame column
400x244 LVL frame beam
60x60x10 MSEA steel corbel and 5–M12 bolts (typical)
elevation
steel corbel
(level 2 only)
4–SPAX screws x350 long
4–holes under for epoxied M24 grade 4.6 threaded bars
column anchorage
STIC.
HolmesConsultingGroup
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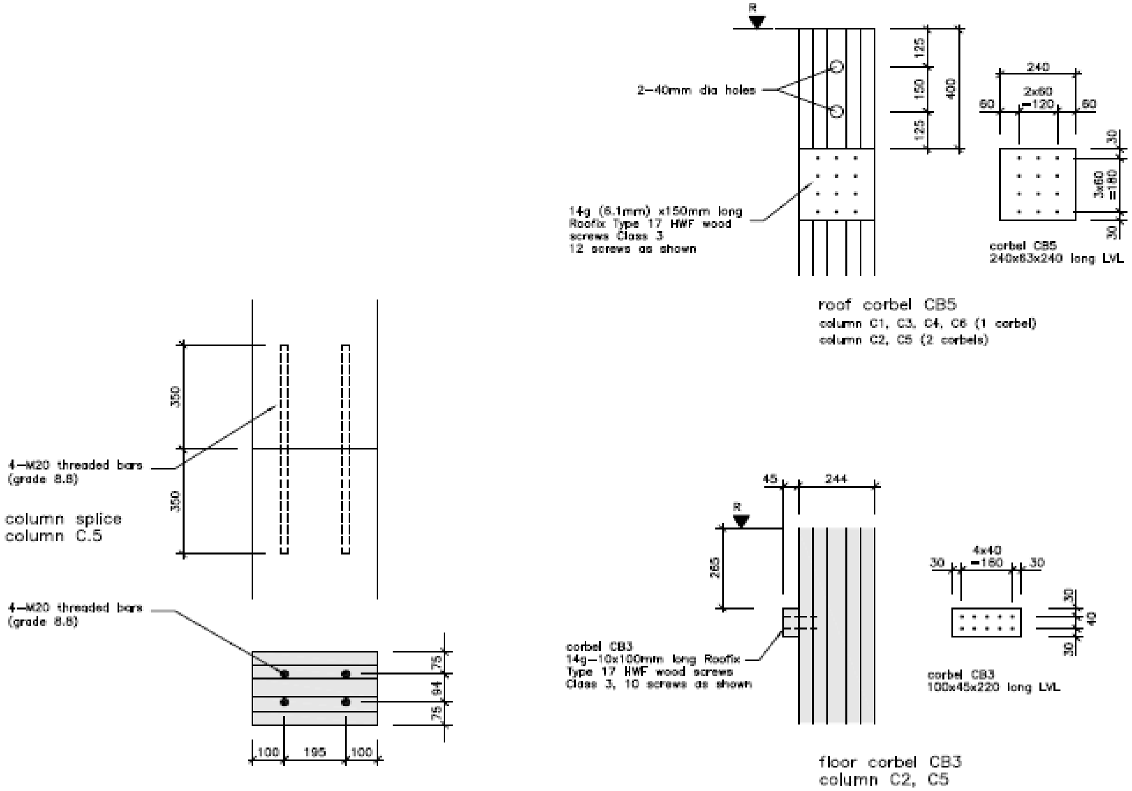
Office Building
University of Canterbury
Christchurch
Column Details
level G, level 1
104658
S4–3
A



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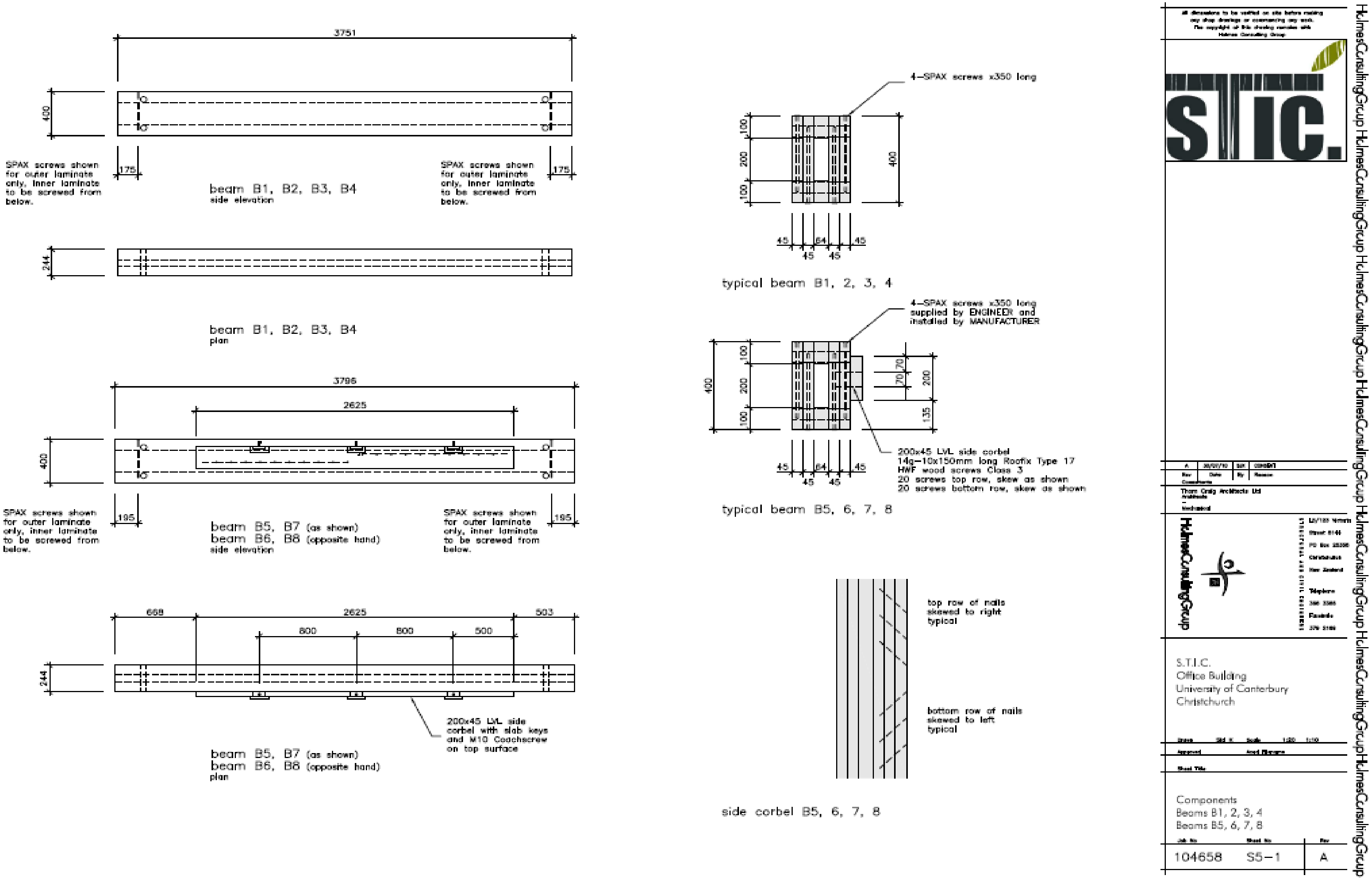
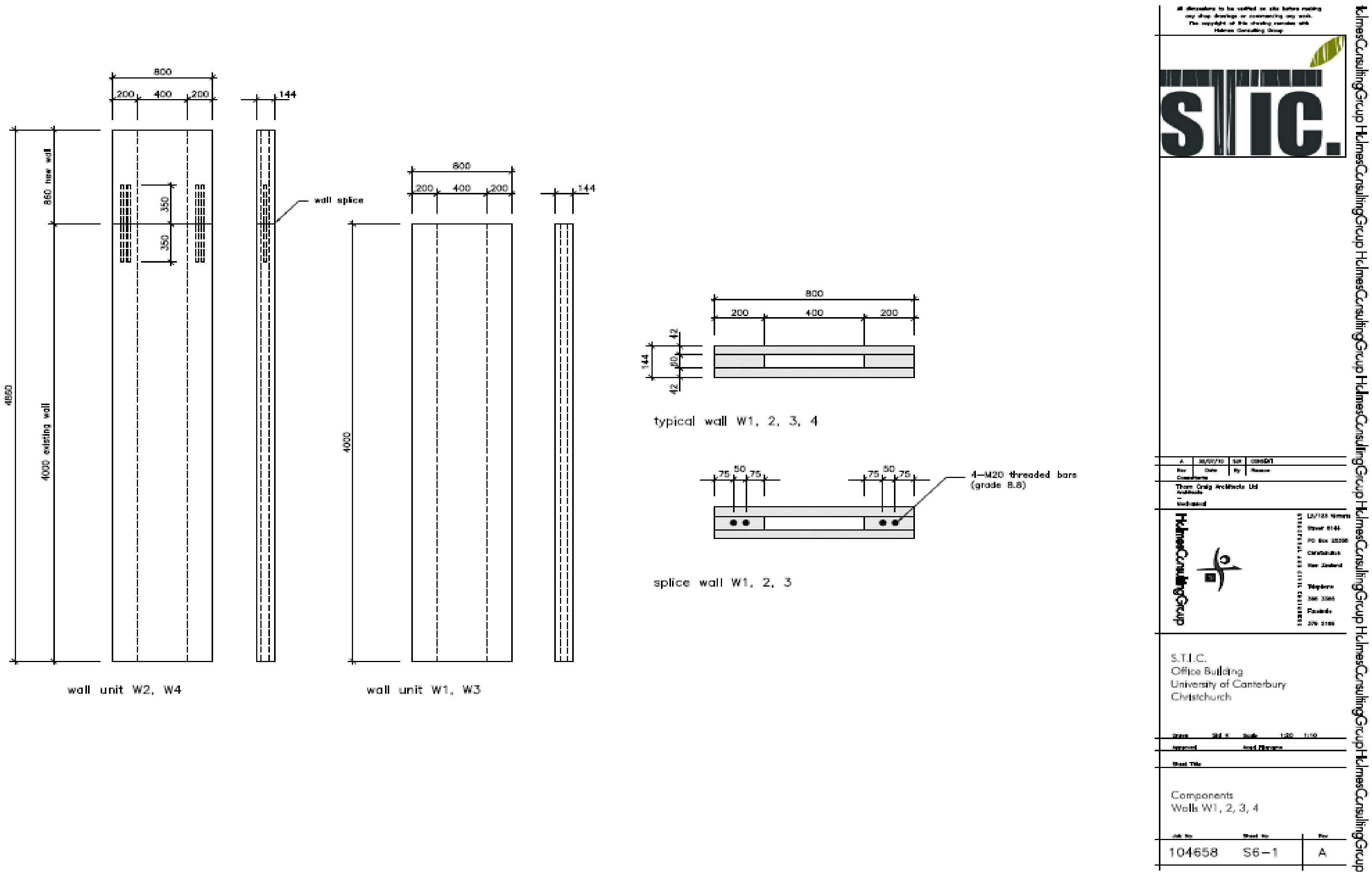
Christchurch

Column Details
Roof

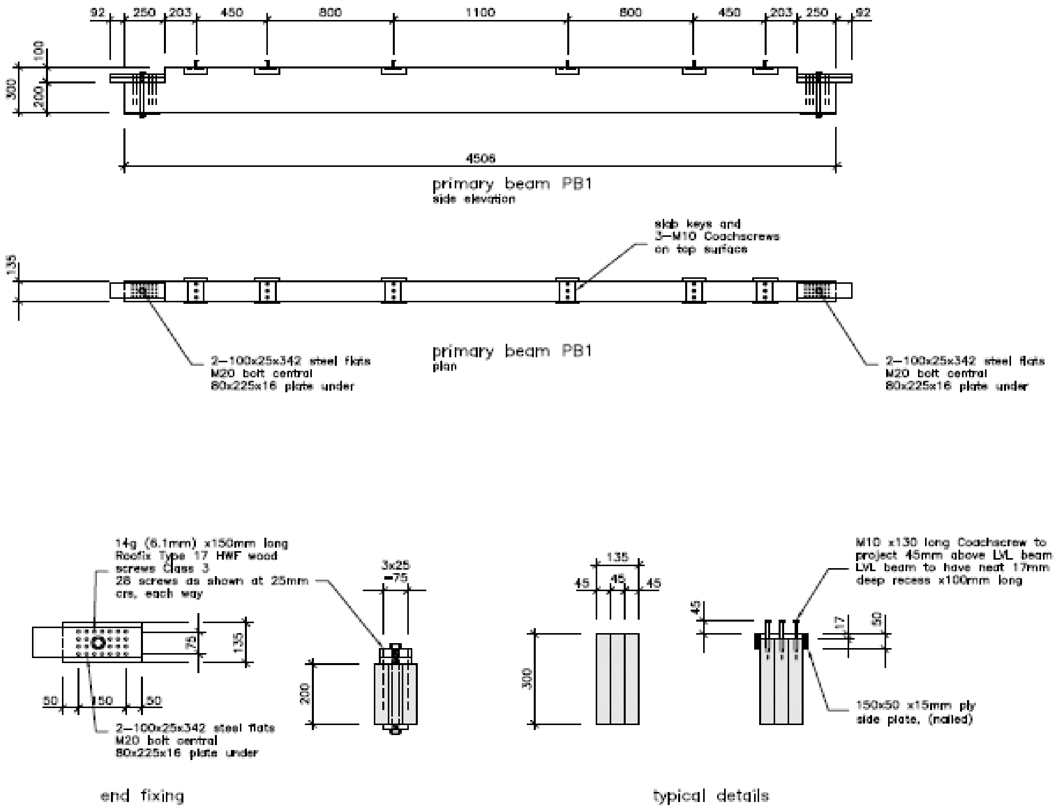
Job No	Sheet No	Rev
104658	S4-4	A

HolmesConsultingGroup


3751
400
SPAX screws shown for outer laminate only, inner laminate to be screwed from below.
175
175
SPAX screws shown for outer laminate only, inner laminate to be screwed from below.
beam B1, B2, B3, B4
side elevation
244
beam B1, B2, B3, B4
plan
3796
2625
400
195
195
SPAX screws shown for outer laminate only, inner laminate to be screwed from below.
beam B5, B7 (as shown)
beam B6, B8 (opposite hand)
side elevation
SPAX screws shown for outer laminate only, inner laminate to be screwed from below.
668
2625
503
800
800
500
244
200x45 LVL side corbel with slab keys and M10 Coachscrew on top surface
beam B5, B7 (as shown)
beam B6, B8 (opposite hand)
plan
4–SPAX screws x350 long
100
200
100
400
45
64
45
45
45
typical beam B1, 2, 3, 4
4–SPAX screws x350 long supplied by ENGINEER and installed by MANUFACTURER
400
100
200
100
70
70
200
135
45
64
45
45
45
200x45 LVL side corbel
14g–10x150mm long Roofix Type 17
HWF wood screws Class 3
20 screws top row, skew as shown
20 screws bottom row, skew as shown
typical beam B5, 6, 7, 8
top row of nails skewed to right typical
bottom row of nails skewed to left typical
side corbel B5, 6, 7, 8
S.T.I.C.
Office Building
University of Canterbury
Christchurch
Components
Beams B1, 2, 3, 4
Beams B5, 6, 7, 8
104658
S5–1
A



800
200
400
200
144
860 new wall
350
350
wall splice
4860
4000 existing wall
4000
wall unit W2, W4
wall unit W1, W3
42
144
60
42
typical wall W1, 2, 3, 4
75
50
4-M20 threaded bars (grade 8.8)
splice wall W1, 2, 3
STIC.
HolmesConsultingGroup
S.T.I.C.
Office Building
University of Canterbury
Christchurch
Components
Walls W1, 2, 3, 4
104658
S6-1
A



STIC.

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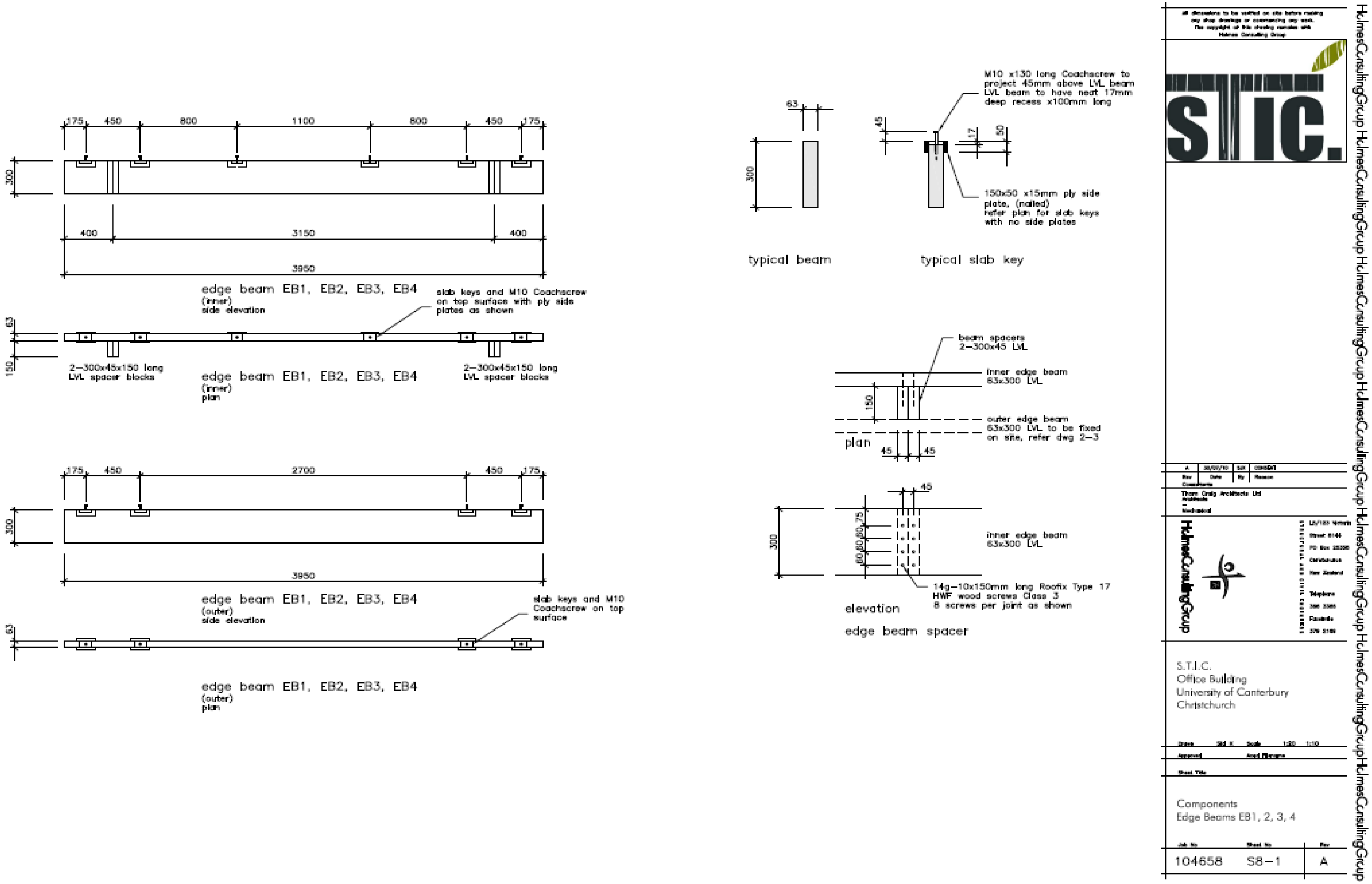
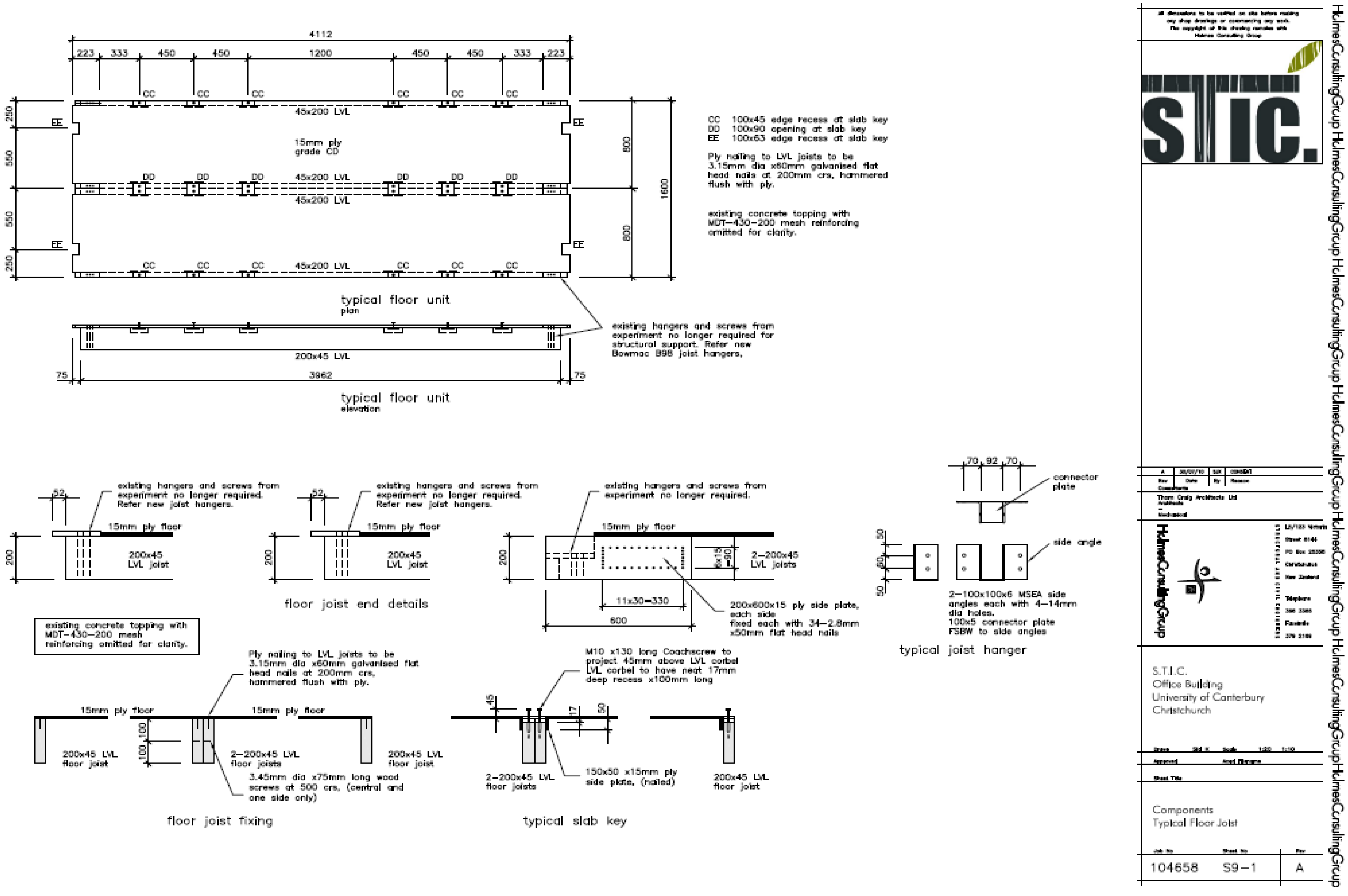
Christchurch

Components
Primary Beam PB1

104658 S7–1 A

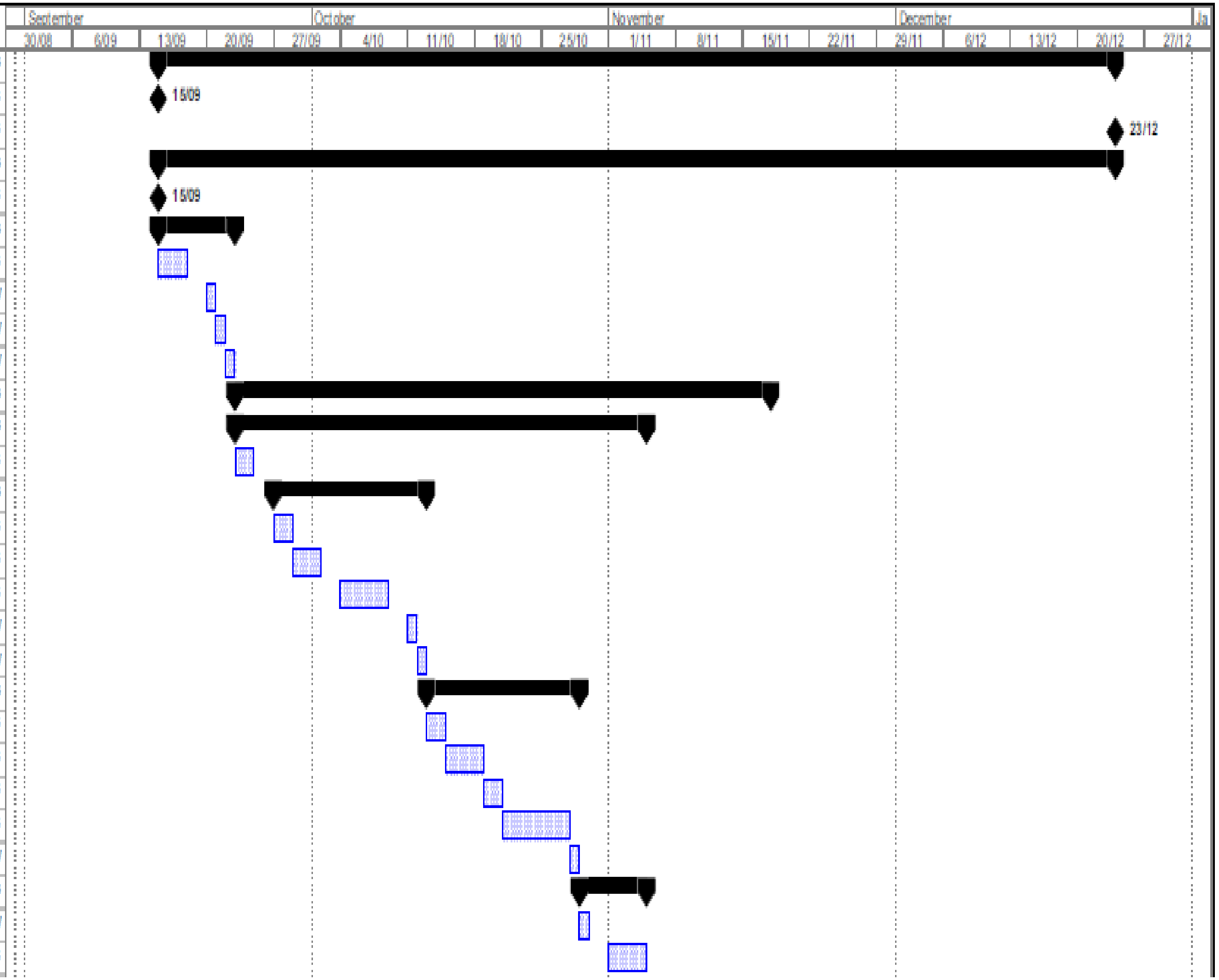

edge beam EB1, EB2, EB3, EB4
(inner)
side elevation
edge beam EB1, EB2, EB3, EB4
(inner)
plan
slab keys and M10 Coachscrew on top surface with ply side plates as shown
2-300x45x150 long LVL spacer blocks
edge beam EB1, EB2, EB3, EB4
(outer)
side elevation
edge beam EB1, EB2, EB3, EB4
(outer)
plan
slab keys and M10 Coachscrew on top surface
typical beam
typical slab key
M10 x130 long Coachscrew to project 45mm above LVL beam LVL beam to have neat 17mm deep recess x100mm long
150x50 x15mm ply side plate, (nailed) refer plan for slab keys with no side plates
beam spacers 2-300x45 LVL
inner edge beam 63x300 LVL
outer edge beam 63x300 LVL to be fixed on site, refer dwg 2-3
plan
inner edge beam 63x300 LVL
14g-10x150mm long Roofix Type 17 HWF wood screws Class 3 8 screws per joint as shown
elevation
edge beam spacer
S.T.I.C.
Office Building
University of Canterbury
Christchurch
Components
Edge Beams EB1, 2, 3, 4
104658
S8-1
A
HolmesConsultingGroup



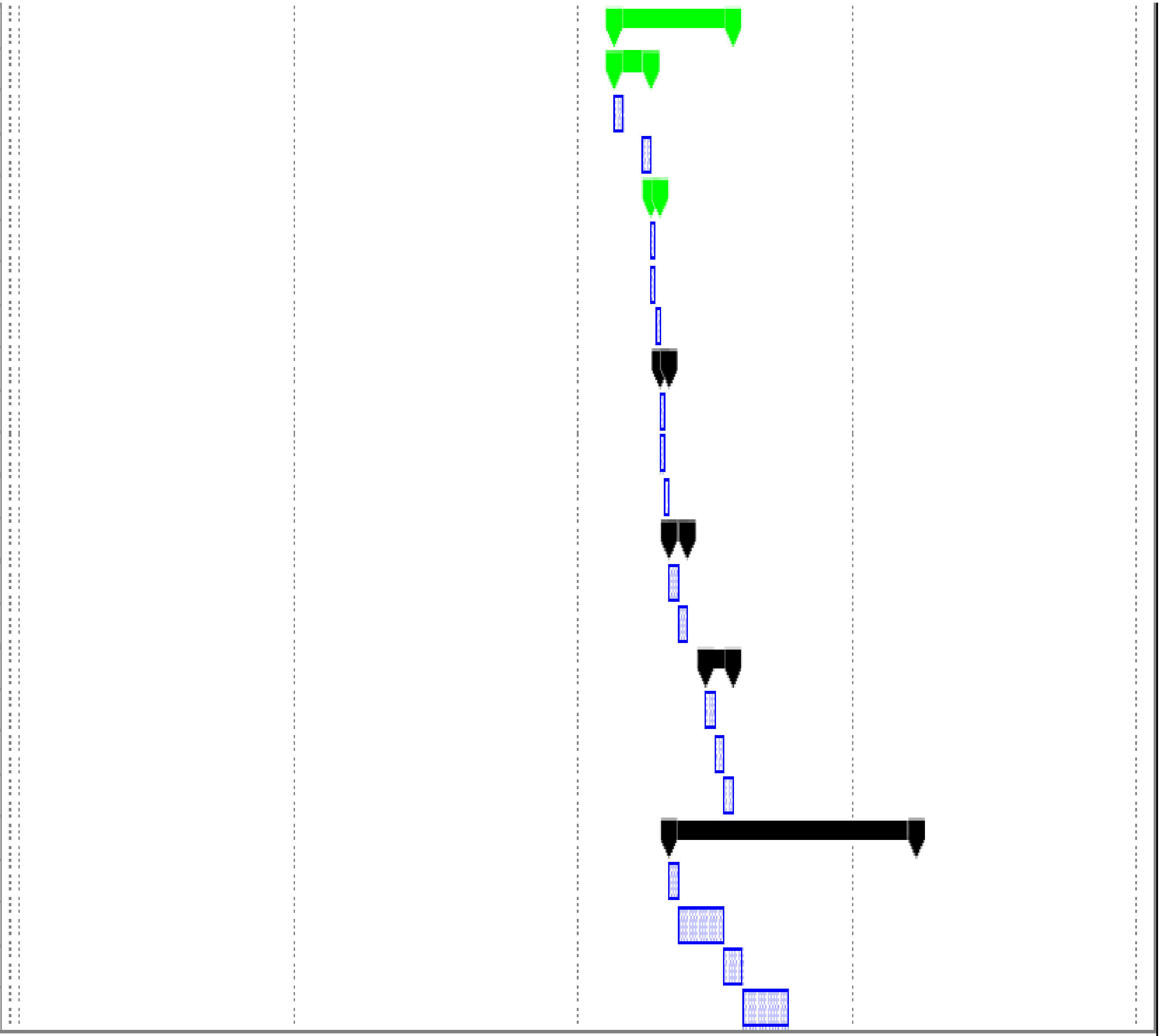
typical floor unit
plan
typical floor unit
elevation
CC 100x45 edge recess at slab key
DD 100x90 opening at slab key
EE 100x63 edge recess at slab key
Ply nailing to LVL joists to be 3.15mm dia x60mm galvanised flat head nails at 200mm crs, hammered flush with ply.
existing concrete topping with MDT-430-200 mesh reinforcing omitted for clarity.
existing hangers and screws from experiment no longer required for structural support. Refer new Bowmac B98 joist hangers.
floor joist end details
typical joist hanger
floor joist fixing
typical slab key
S.T.I.C.
Office Building
University of Canterbury
Christchurch
Components
Typical Floor Joist
104658
S9-1
A

Appendix 18: Reconstruction Programme for the STIC Building

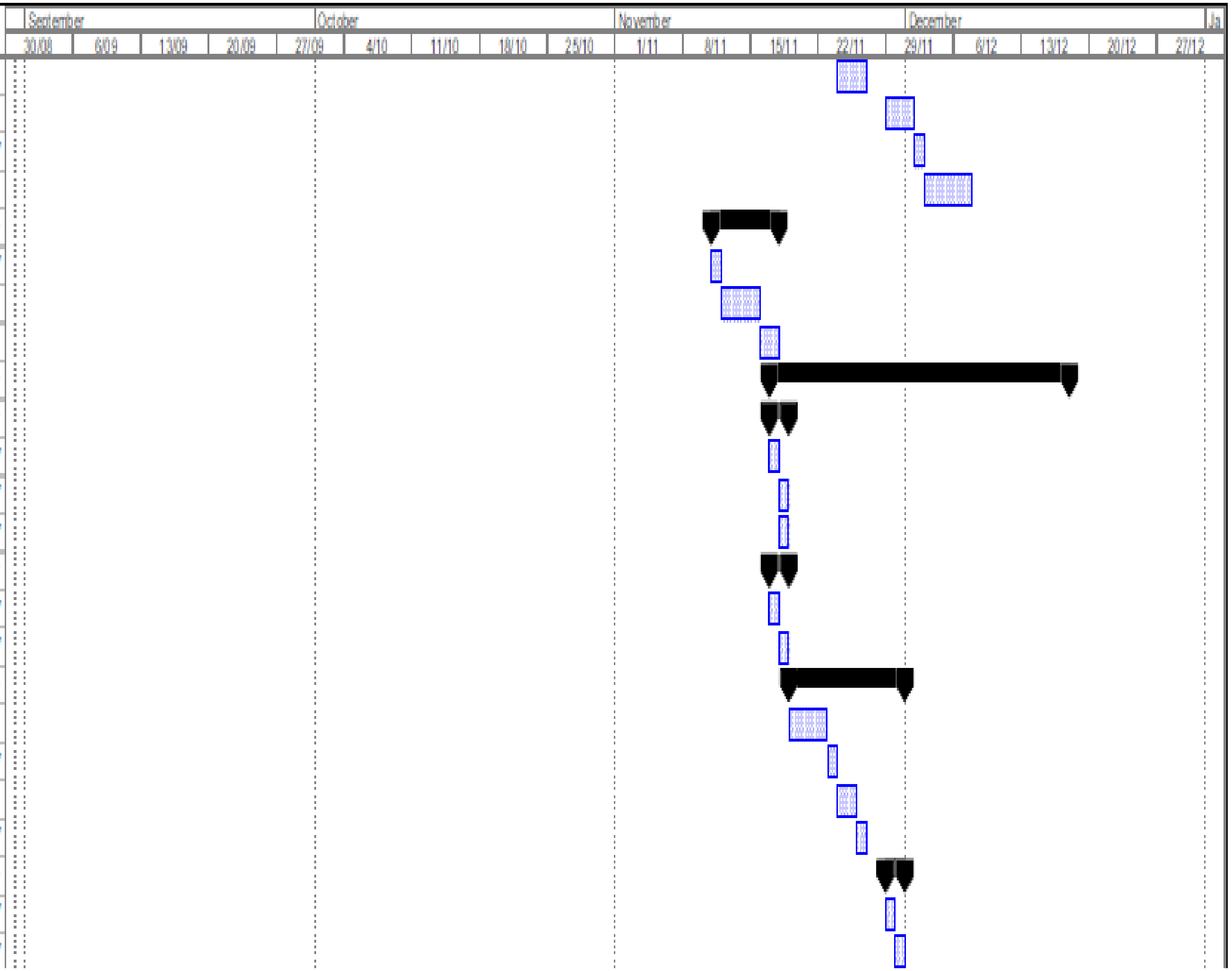
ID	Task Name	Duration
1	**PROJECT DURATION**	**72 days**
2	start	0 days
3	Handover to STIC	0 days
4	**CONSTRUCTION**	**72 days**
5	Site Made Available by STIC	0 days
6	**Site establisment & Enabling work**	**6 days**
7	Mobilisation	3 days
8	setting out	1 day
9	erect Temp. hoarding/fencing	1 day
10	site clearing	1 day
11	**Structure**	**40 days**
12	**Substructure**	**31 days**
13	excavation	2 days
14	**Strip Foundation Beams & footings**	**12 days**
15	Formwork	2 days
16	Place reinforcing	3 days
17	Pour Beam (allow for curing)	5 days
18	Strip	1 day
19	Backfilling	1 day
20	**Column and wall Plinths**	**12 days**
21	Place reinforcing	2 days
22	Formwork	2 days
23	Insert hold down bolts	2 days
24	Pour Beam (allow for curing)	5 days
25	Strip	1 day
26	**Wooden Ground Floor**	**5 days**
27	preparation work	1 day
28	Carpentery work	4 days



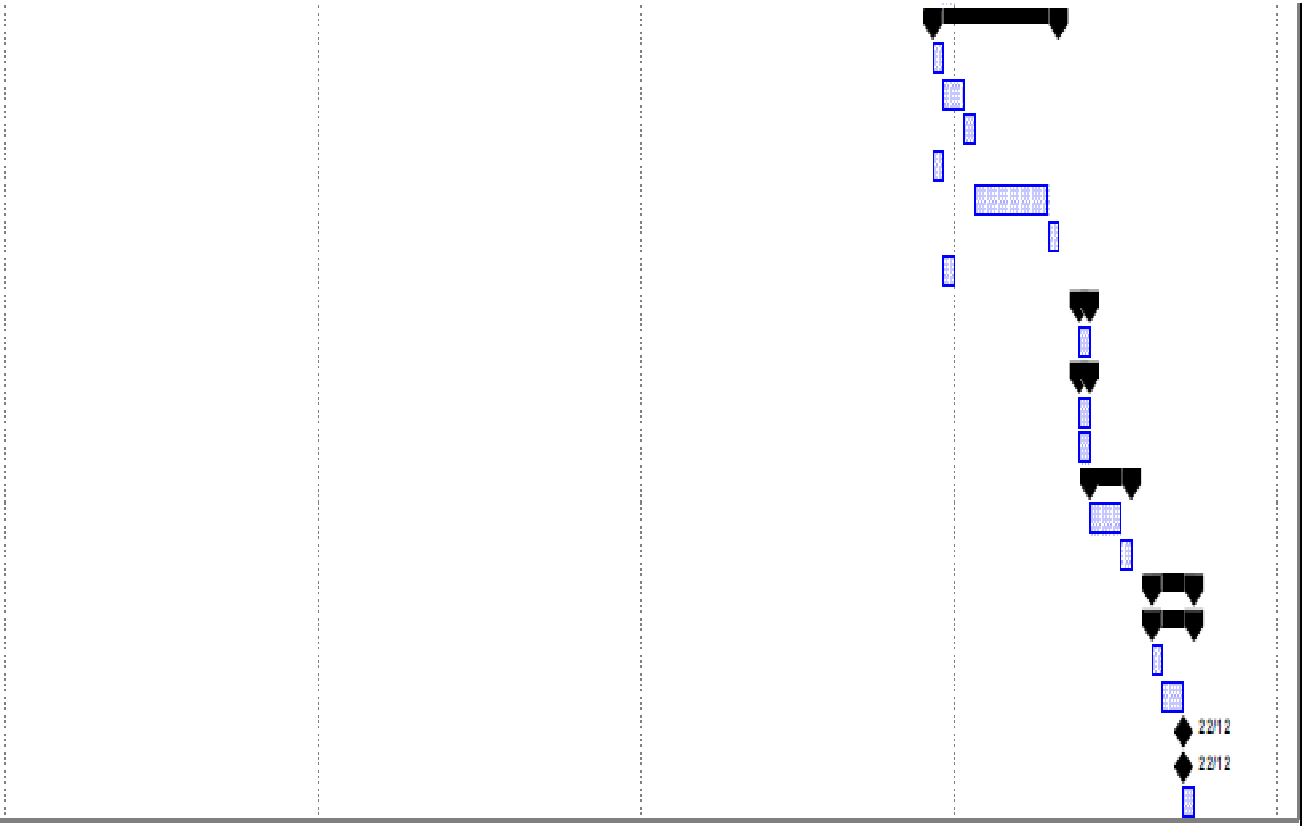
29	**Structural Pres-Lam system**	**9 days**
30	**Ground floor**	**2 days**
31	Base preparation at column plinth	1 day
32	Install columns and end frames (walls)	1 day
33	**First Floor**	**1 day**
34	Install 1st floor beams	0.5 days
35	Fix joist hangers	0.5 days
36	1st floor- TCC floor panels placed	0.5 days
37	**Roof level**	**1 day**
38	Install Roof beams	0.5 days
39	Fix joist hangers	0.5 days
40	Roof level- Placed TCC floor panels	0.5 days
41	**Post-tensioning works**	**2 days**
42	Place MacAlloy Bars to beams and walls	1 day
43	Stressed/tighten MacAlloy bars	1 day
44	**Floors concrete joists**	**3 days**
45	Preparation work	1 day
46	lay wiremesh & others	1 day
47	Pour concrete to all concrete joints	1 day
48	**Building Envelope -external wall**	**19 days**
49	Complete Scaffold	1 day
50	Alum studs Framing for PSP flexiglas cladding	3 days
51	External wall batten for ECOPLY	2 days
52	Install rainscreen system (12.5mm plasterboard)	3 days



ID	Task Name	Duration
53	external wall painting	3 days
54	Install Acrylic borrowed light	3 days
55	Remove scaffold	1 day
56	Install PSP flexiglas glazing (acrylic cladding)	3 days
57	**Roof Top waterproofing**	**5 days**
58	Install 17mm construction plywood	1 day
59	Install 100mm EPS on graded mortar	2 days
60	Lay BUTYL Rubber	2 days
61	**Internal works**	**23 days**
62	**Ground floor**	**2 days**
63	wall framing and lining	1 day
64	Insulation	1 day
65	40mm Triboard wall	1 day
66	**G/F Services**	**2 days**
67	Fix cabled services/piped services	1 day
68	Install Main S/Board	1 day
69	**1st Floor**	**8 days**
70	wall framing and lining	2 days
71	Insulation	1 day
72	Install Alum. Grating at perimeter	2 days
73	40mm Triboard wall	1 day
74	**1st Floor Services**	**2 days**
75	Fix cabled services/piped services	1 day
76	Install Main S/Board	1 day



77	**Finishes and Fit out**	**10 days**
78	Fit door frames	1 day
79	Plasterboard linings, Fix/stop	2 days
80	skirtings, trim etc	1 day
81	suspended ceiling grid	1 day
82	Painting	5 days
83	Applied Vinyl flooring	1 day
84	Install ceiling and Insulation	1 day
85	**FF & E (STIC)**	**1 day**
86	Install all loose furniture	1 day
87	**Services 2nd fix**	**1 day**
88	Fit off plumbing	1 day
89	Install Electrical-lightings/TV/IT	1 day
90	**External works**	**4 days**
91	Construction of Wooden Ramp	3 days
92	make good site & N/bouring prop	1 day
93	**Prepare for Handover**	**4 days**
94	**Code Compliance**	**4 days**
95	Apply for CoC	1 day
96	CoC Process Period	2 days
97	Obtain CPU	0 days
98	COC Approval	0 days
99	Commisioning and Hand over to STIC	1 day



Project: Project timber 6 storey Biolog
Date: Tue 31/08/10

Task		Milestone		Rolled Up Task		Rolled Up Progress		External Tasks		Group By Summary	
Progress		Summary		Rolled Up Milestone		Split		Project Summary		Deadline	

Appendix 19: Quotation for PSP Multiwall Cladding System for STIC Building

PSP

9th August 2010

PSP Wellington
72 Hammersmith Drive
Sockburn
Christchurch

PO Box 2841
Christchurch

Ph. 03 341 0248
Fax. 03 341 0257

Email. mel@psp.co.nz

Ricky Wong (Student)
University of Canterbury
Department of Civil and Natural Resources Engineering
Private Bag 4800
Christchurch 8140

Plexiglas Multiwall & PSP Glazing Bar Quotation

Dear Ricky
Thank you for your quotation request, the prices for your selected Plexiglas Multiwall SDP16 complete with the PSP Glazing system as listed below:

Option 1
15 sheets of Plexiglas clear Multiwall SDP16 3200 x 1200 @ $ 491.18 per sheet
16 lengths of PSP glazing system bars 3200 long mill finish @ $ 120.45 per bar

Option 2
20 sheets of Plexiglas clear Multiwall SDP16 3200 x 1200 @ $ 491.18 per sheet
21 lengths of PSP glazing system bars 3200 long mill finish @ $120.45 per bar

Option 3
5 sheets of Plexiglas clear Multiwall SDP16 3200 x 1200 @ $ 491.18 per sheet

The Plexiglas clear Multiwall sheet that we carry ex stock here is New Zealand is available in 3000mm and 4000mm lengths only.
The price for the above is based on 4000mm lengths.

If it is possible to re design to allow for 3000mm lengths there is a significant saving.
These sheets are priced @ $368.42 per sheet.
The same goes for the glazing bar system this is available in 4000mm 5000mm and 6000mm lengths.
3000mm lengths priced at $90.34 per bar.
Prices do not include GST
Freight Free into store Christchurch.
Quotation valid for 30 days only,

As for your other request unfortunately we are only sheet importers and we do not install our products.
Any of the larger local glass merchants have the ability to install this system.
If you have any additional questions do not hesitate to ask.

Yours sincerely
Mel Jackson
South Island Sales Manager

Appendix 20: Estimated Reconstruction Costs

UoC STIC Building

ESTIMATE SUMMARY

STRUCTURE				
T	STIC BUILDING		$	230,193.07
			$	230,193.07
ELEMENT				
T02	SUBSTRUCTURE		$	31,351.30
T03	Structural LVL FRAME & WALLS		$	58,602.77
T04	POST-TENSIONING WORKS		$	10,300.00
T05	UPPER FLOORS		$	11,950.00
T06	ROOF		$	18,255.00
T07	EXTERIOR FINISH		$	35,904.00
T08	WINDOW AND EXTERIOR DOORS		$	6,720.00
T09	STAIRS AND BALUSTRADES		$	10,400.00
T10	INTERIOR WALLS		$	17,850.00
T11	INTERIOR DOORS		$	2,400.00
T12	FLOOR FINISHES		$	440.00
T13	CEILING FINISHES		$	2,700.00
T14	SANITARY PLUMBING		$	5,200.00
T15	ELECTRICAL SERVICES		$	9,600.00
T16	SPECIAL SERVICES		$	3,000.00
T17	DRAINAGE		$	3,600.00
T18	EXTERNAL WORKS		$	1,920.00
		Total	$	230,193.07
	PRELIMINARIES AND MARGIN	(13% of Total)	$	29,925.10
		Subtotal	$	260,118.17
		GRAND TOTAL	$	260,118.17

UoC STIC Building

T 02 STRUCTURE ELEMENT SUBSTRUCTURE

Item	Item Description	Quantity	Unit		Rate		Amount
1	800 x800x 500 deep reinforced concrete pad foundations formwork, excavation and disposal	6	no	$	330.00	$	1,980.00
2	400 x 500 deep reinforced concrete foundations including formwork, excavation and disposal to grid lines 1 and 2	13.5	m	$	300.00	$	3,118.00
3	400 x 500 deep reinforced concrete foundations including formwork, excavation and disposal to grid lines A and C	8.3	m	$	300.00	$	2,490.00
4	400 x 400 x 200 deep reinforced concrete pad foundations including formwork, excavation and disposal	14	no	$	90.00	$	1,260.00
5	Allow for supply and labour to install 125mm square timber piles H5 Treated	13	no	$	47.00	$	611.00
6	600 x 600 x 1475 high reinforced concrete column plinth. Formwork, backfill and included 4-M20 hold down bolts with anchors	6	no	$	850.00	$	5,100.00
7	1820 x 250x 1570 high reinforced concrete wall plinth, formwork and backfill	2	no	$	890.00	$	1,780.00
8	Allow for supply and install 4-M25 MacAlloy 1030 bars to wall plinths with 800mm embeded length with 100x100x 20mm washers	2	no	$	400.00	$	800.00
9	Allow for supply and erect 190x45mm Bearers H1.2 Treated, included fixing 2/4.9mm wire dogs & 2/100 x 3.75mm nails to timber piles	25.2	m	$	59.00	$	1,486.80
10	Allow for supply and erect 190x45mm floor joists @ 400 crs, H1.2 Treated, included fixings	191	m	$	30.50	$	5,825.50
11	Allow for supply and install 17mm plywood to ground floor included with 50mm R1.44 GOLDFOAM XPS insulation	60	m2	$	115.00	$	6,900.00
			Total for SUBSTRUCTURE			$	31,351.30

T 03 STRUCTURE ELEMENT LVL FRAME and Walls

12	Allow Cost for LVL components (Columns, Beams, walls and TCC floor units)-say	1	LS	$	50,000.00	$	50,000.00
13	Allow for labour and crane to erect 395x 244 x 4760 long LVL column in place, include to insert the column-beam steel plate at level 1.	28.56	m	$	47.00	$	1,342.32
14	Allow for labour and crane to assemble and to erect LVL frame consisting of 2x (800 x 144 x 4760 long LVL wall) and 4 x (63mmx 300mm x 4000 long LVL egde beams) in place	0.77	m3	$	2,285.00	$	1,759.45
15	Allow for labour and crane to erect 395 x 244 LVL beam	38.5	m	$	26.00	$	1,001.00
16	Allow to assemble 4 -M 20 expoxied mild steel into LVL column that come with 20mm base connection plate	6	no	$	250.00	$	1,500.00
17	Allow for Temporary bracing for columns and walls and other Miscellanous for connections	1	LS	$	3,000.00	$	3,000.00
			Total for FRAME			$	58,602.77

T 04 STRUCTURE ELEMENT POST-TENSIONING WORKS

18	Mobilisation	1	LS	$	1,200.00	$	1,200.00
19	Allow Labour and supervisor	2	per day	$	900.00	$	1,800.00
20	End bearing anchorages plates	12	no	$	200.00	$	2,400.00
21	consumables	2	day	$	50.00	$	100.00
22	M25mm dia. x 9.5 m length Macalloy 1030 bars to beam	76	m	$	35.00	$	2,660.00
23	M25mm dia. x 9.5 m length Macalloy 1030 bars to wall	40.8	m	$	35.00	$	1,428.00
24	M25-MacAlloy 1030 -washer and nuts	16	no	$	22.00	$	352.00
25	MacAlloy 1030 -25mm couplers	8	no	$	45.00	$	360.00
			Total for POST-TENSIONING WORKS			$	10,300.00

UoC STIC Building

T 05 STRUCTURE ELEMENT UPPER FLOOR

26	Allow for labour and crane to erect TCC floor panels	72	m2	$	40.00	$	2,880.00

27	Allow for temporary supports or props to floor units	1	LS	$	500.00	$	500.00
28	Allow for supply and fixing of specially fabricated steel joist hanger to structural LVL beam	34	no	$	55.00	$	1,870.00
29	Allow for supply , fixing reinforcement and to pour new 50mm concrete topping to perimeter strips	27	m	$	100.00	$	2,700.00
30	Allow for supply and install 30 x 3 mm Aluminuim grating to perimeter of first floor, including double 90 x 45mm struts @ 1.2m crs with steel bracket fabricated from 6mm fixed with 2M12 coach screws to existing LVL beam	16	m2	$	250.00	$	4,000.00
				Total For TIMBER UPPER FLOOR		$	11,950.00
T 06	STRUCTURE ELEMENT ROOF						
31	Roof parapet panels comprising 150 thick x 400 mm upstand is fixed to existing structure with 2m12 chemset bolts embedded 100mm with 150mm spaced. Framed in 100 x 25mm battens, with GoldFoam XPS 50mm EPS insulated, lined both sides with HARDIES 6mm villa board, painted.	12.4	m2	$	250.00	$	3,100.00
32	1.0 mm Butyl rubber on 17mm CCA Const. grade ply adhesive fixed to 100mm EPS graded mortar on existing roof structure	46	m2	$	160.00	$	7,360.00
33	ø 100mm downpipes withn IMT 100 scupper outklet to gutter & IMT200 scupper outlet bend	12	m	$	110.00	$	1,320.00
34	PSP FLEXIGLAS RESIST SDP 16 CLEAR ACRYLIC, OPENING PANEL IN ANOD Al. GLAZING BARS SUPPORTED BY DOUBLE 90X45 LVL STRUTS 21.2M CRS TO PERIMETER OF ROOF	18.5	m2	$	350.00	$	6,475.00
				Total For ROOF		$	18,255.00
T07	STRUCTURE ELEMENT **EXTERIOR FINISH**						
35	Allow for external scalffoding to building envelope	1	LS	$	1,000.00	$	1,000.00
36	Type P1- FLEXIGLAS RESIST SDP 16 CLEAR ACRYLIC IN ANOD. AL. PSP GLAZING SYSTEM ON LAMINATED TIMBER MULLIONS	57.6	m2	$	330.00	$	19,008.00
37	TYPE P2- 12MM H3.2 LOSP"ECOPLY" PREFAB. PANELS WITH SELECTED FN ADHESIVE FIXED TO 50MM E.P.S INSUL ADHESIVE FIXED TO HARDIES 6MM VILLA BD WITH SELECTED PAINT FN IN ANOD. AL. PSP GLAZING SYSTEM ON LAMINATED TIMBER MULLIONS	76.8	m2	$	220.00	$	16,896.00
38	Extra value for 338 (75mm square) mesh to perimeter around the foundation beams of the lower external cladding	28	m	$	33.00	$	924.00
39	Extra value for ANOD.Al Flashing at outer corner of the building envelope	18	m	$	120.00	$	2,160.00
				Total for EXTERIOR FINISH		$	35,904.00
T 08	STRUCTURE ELEMENT **WINDOW AND EXTERNAL DOORS**						
40	TYPE P3- FLEXIGLAS RESIST SDP 16 CLEAR ACRYLIC, OPENING PANEL IN AL TRIM TO PERIMETER WITH RESTRICTOR STAYS	19.2	m2	$	350.00	$	6,720.00
				Total For WINDOWS AND EXTERIOR DOORS		$	6,720.00

UoC STIC Building

T 09	STRUCTURE ELEMENT **STAIRS AND BALUSTRADES**						
41	Proprietry "Artistic" Spiral stair (ø1.0 mm o/a) with closed risers & (REF. SHT A5 for detail) 15 risers @181mm=2720mm All goings @280mm (say)	1	LS	$	8,000.00	$	8,000.00
42	Internal handrail -1.0m high rails formed from ø 40 Paint FIN. Galv. Tube with posts @ 1.2m crs approx. with ø 80 x 8mm Paint Fin. Gal. base plate fixed with 21 M 16 coach screws to one level	5	m	$	480.00	$	2,400.00
				Total For STAIRS AND BALUSTRADES		$	10,400.00
T 10	STRUCTURE ELEMENT **INTERIOR WALLS**						
43	Internal partition, 40mm Triboards wall, framed in 25mm batten, lined both sides with GIB plasterboard, painted.	11	m2	$	135.00	$	1,485.00

44	Extra for 1.0 m high PSP flexiglass resist SDP 16 clear acrylic barrier	1.2	m2	$	250.00	$	300.00
45	Toilet full partition with 100x 50mm frame, lined both sides with 13mm GIB and painted	17	m2	$	145.00	$	2,465.00
46	Paint on internal surface of 6mm Hardies board -part of PSP system and timber mullions and storage walls	85	m2	$	160.00	$	13,600.00
					Total For INTERIOR WALLS	$	**17,850.00**
T 11	STRUCTURE ELEMENT **INTERIOR DOORS**						
47	860mm cavity sliding doors including frame, hardware and finish	2	no	$	1,200.00	$	2,400.00
					Total For INTERIOR DOORS	$	**2,400.00**
T 12	STRUCTURE ELEMENT **FLOOR FINISHES**						
48	Seam welded vinyl cover 150mm up walls with Treadsafe DT061 Detail Trim-Charcoal	4	m2	$	110.00	$	440.00
					Total For FLOOR FINISHES	$	**440.00**
T 13	STRUCTURE ELEMENT **CEILING FINISHES**						
49	SUSP. 13mm Acoustic Gyprock ceiling on Rondo ceiling battens @ 600crs on Furring channel fixed to U/S on exist. Structure with 50mm glass wool acoustic insul. To top	13.5	m2	$	200.00	$	2,700.00
					Total For CEILING FINISHES	$	**2,700.00**
T 14	STRUCTURE ELEMENT **SANITARY PLUMBING**						
50	Water Supply (say)	1	LS	$	1,200.00	$	1,200.00
51	Caroma care 400WC Toilet pan and cistern complete with water and waste services and paper holder	1	no	$	2,500.00	$	2,500.00
52	Caroma Integra 500 Wash hand basin complete with water and waste services come with 6mm Pol. Edge mirror	1	no	$	1,200.00	$	1,200.00
53	Φ30mm S.S Grab rail	1	no	$	300.00	$	300.00
					Total For SANITARY PLUMBING	$	**5,200.00**
T 15	STRUCTURE ELEMENT **ELECTRICAL SERVICES**						
54	Electric power and lighting including submains and swithboards	80	m2	$	120.00	$	9,600.00
					Total For ELECTRICAL SERVICES	$	**9,600.00**
T 16	STRUCTURE ELEMENT **SPECIAL SERVICES**						
55	Telephone and data/comms system (say)	1	LS	$	1,000.00	$	1,000.00
56	LCD 40" TV	2	no	$	1,000.00	$	2,000.00
					Total For SPECIAL SERVICES	$	**3,000.00**
T 17	STRUCTURE ELEMENT **DRAINAGE**						
57	Sewer and storm water drainage -(Φ90 S.W and Φ100 S.P)	30	m	$	120.00	$	3,600.00
					Total For DRAINAGE	$	**3,600.00**
T 18	STRUCTURE ELEMENT **EXTERNAL WORKS**						
58	10m long wooden Deck Excess Ramp	12	m2	$	160.00	$	1,920.00
					Total For EXTERNAL WORKS	$	**1,920.00**
					Subtotal For STIC BUILDING	$	**230,193.07**
					TOTAL	$	**230,193.07**
	PRELIMINARIES AND MARGIN				(13.00% of Total)	$	**29,925.10**
					Subtotal	$	**260,118.17**
					GRAND TOTAL For STIC BUILDING	$	**260,118.17**

Appendix 20.1: Spread Sheet for Taking-off Quantity for STIC Building

Description

Excavation in	Location	no	depth	width	length	Vol. (m^3)	unit rates/m3	$ (unit)/no
800 x800 pad foundations	C1,2,3,4,5,6	6	0.7	0.8	0.8	3.23	$ 20.75	$ 11
400x500 foundation s beams GL 1-2	GL 1 & 2	2	0.7	0.4	13.5	9.07	$ 20.75	$ 94
400x500 foundation s beams GL A & C	GL A & C	2	0.7	0.4	8.3	5.58	$ 20.75	$ 58
400x400x200 deep small footings		14	0.2	0.4	0.4	0.54	$ 20.75	$ 1

Concrete in	Location	no	depth	width	length	Vol. (m^3)	unit rates/m3	$ (unit)/no
Small footings for timber piles		13	0.2	0.4	0.4	0.42	$ 240.00	$ 8
Footings for staircase		1	0.7	0.5	0.5	0.18	$ 240.00	$ 42
Footings	C1,2,3,4,5,6	6	0.6	0.8	0.8	2.30	$ 240.00	$ 92
Foundation beams	GL 1 & 2	2	0.5	0.4	6.782	2.71	$ 240.00	$ 326
Foundation beams	GL A & C	2	0.5	0.4	4.153	1.66	$ 245.00	$ 203
Column plinths	C1,2,3,4,5,6	6	0.6	0.6	1.475	3.19	$ 245.00	$ 130
Wall plinths	C1,2,3,4,5,6	2	1.82	0.25	1.56	1.42	$ 245.00	$ 174

Reinforcements in	Location	no	no. of Reo	Type & dia. (mm)	length (m)	unit weight (kg/m)	Weight (kg)	unit rates/tonne	$ (unit)/single item	Total $ (unit)/no
Small Footings		14								
Footings in foundation beams-corner	C1,2,5,6	4	8	T/B-XD 16	1	1.579	$ 51	$ 3,140	$ 40	$ 68
		4	4	U bars-XD 12	2.1	0.888	$ 30	$ 3,805	$ 28	
Footings in foundation beams-middle	C3,4	2	12	T/B-XD 16	1	1.579	$ 38	$ 3,140	$ 59	$ 88
		2	4	U bars-XD 12	2.1	0.888	$ 15	$ 3,805	$ 28	
Foundation beams	GL A & C	2	10	XD16	5.5	1.579	$ 174	$ 3,140	$ 273	$ 436
		2	28	2-XR10-200	2.3	0.616	$ 79	$ 4,110	$ 163	
Foundation beams	GL 1 & 2	2	10	XD16	9	1.579	$ 284	$ 3,140	$ 446	$ 714
		2	46	2-XR10-200	2.3	0.616	$ 130	$ 4,110	$ 268	
Column plinths (600 x600)	C1,2,5,6	6	12	XD 20	1.975	2.466	$ 351	$ 3,150	$ 184	$ 324
		6	8	3-XR12-200	5.18	0.888	$ 221	$ 3,805	$ 140	
Wall plinths (1820x 250x 1520)		2	7	XD16-275(V)	6.24	2.466	$ 215	$ 3,150	$ 339	$ 437
		2	5	XR12-300 (H)	5.8	0.888	$ 52	$ 3,805	$ 98	

Formwork in	Location	no	depth	width	length	Area (m^2)	unit rates/m2	$ (unit/no)
Footings (400x400)		13	0.2	0.4	0.4	2.08	$ 78.00	$ 12
Footings for staircase		1	0.7	0.5	0.5	0.7	$ 78.00	$ 55
Footings (800x800)	C1,2,3,4,5,6	6	0.6	0.8	0.8	5.76	$ 78.00	$ 75

Foundation beams	GL 1 & 2	2	0.5	0.4	6.782	7.182	$ 118.30	$ 425
Foundation beams	GL A & C	2	0.5	0.4	4.153	4.553	$ 118.30	$ 269
Column plinths	C1,2,3,4,5,6	6	0.6	0.6	1.475	7.47	$ 118.30	$ 147
wall plinths		2	1.82	0.25	1.57	6.6248	$ 118.30	$ 392

Wooden Floor	unit	no	depth	width	length	Total (m)	Area (m^2)	unit rates/m2	$ (unit/no)
125mm sq Timber piles, H5 Treated									
		13			0.4	5.2		44/m	
Labour to install piles	0.3 hrs/no	13							$ 24.00
190x45mm Bearers h1.2 Treated, Fixed to piles		3	190	45	8.4	25.2		$ 30.50	
Material for 2/4.9mm wire dogs & 2/100 x 3.75mm nails	sets	13							$ 35.00
Labour to fixed	0.25 hrs/set	13							$ 20.00
190x45 floor joists @ 400 CRS, H1.2 Treated		31	190	45	6.15	190.65		$ 30.50	
Material	17.50/m								$ 17.50
Labour	0.16 hrs/m								$ 13.00
17mm plywood	$61/m2	25		6.15	9.6		59.04	$ 85.00	
labour	0.3hrs/m2								$ 24.00

External Cladding	Location	no	depth	width (m)	length(r	Area (m^2)
Type P1- FLEXIGLAS RESIST SDP 16 CLEAR ACRYLIC IN ANOD. AL. PSP GLAZING SYSTEM ON LAMINATED TIMBER MULLIONS		15		1.2	3.2	57.6

TYPE P2- 12MM H3.2 LOSP"ECOPLY" PREFAB. PANELS WITH SELECTED FN ADHESIVE FIXED TO 50MM E.P.S INSUL ADHESIVE FIXED TO HARDIES 6MM VILLA BD WITH SELECTED PAINT FN IN ANOD. AL. PSP GLAZING SYSTEM ON LAMINATED TIMBER MULLIONS			20		1.2	3.2	76.8	
TYPE P3- FLEXIGLAS RESIST SDP 16 CLEAR ACRYLIC, OPENING PANEL IN AL TRIM TO PERIMETE WITH RESTRICTOR STAYS			5		1.2	3.2	19.2	
SUSP. 13mm Acoustic Gyprock ceiling on Rondo ceiling battens @ 600crs on Furring channel fixed to U/s on exist. Structure with 50mm glass wool acoustic insul. To top					4.2	3.2	13.44	$200/m2
Internal partition, 40mm Triboards wall, framed in 25mm batten, lined both sides with GIB plasterboard, painted.					4.2	2.3	9.66	$120/m2
40mm Triboards wall	first level second level				4.2	2.4	10.08	
1.0 mm Butyl rubber on 17mm h3.2 CCA Construction Plywood adhesive fixed to 100mm EPS insul on graded mortar to existing roof structure							64	
PSP FLEXIGLAS RESIST SDP 16 CLEAR ACRYLIC, OPENING PANEL IN ANOD Al. GLAZING BARS SUPPORTED BY DOUBLE 90X45 LVL STRUTS 21.2M CRS TO PERIMETER OF ROOF					0.6	31	18.6	
Parapet Roof-The parapet wall is fixed to existing structure with 2m12 chemset bolts embedded 100mm with 150mm spaced. framed in 25mm batten, with GoldFoam XPS 50mm EPS insulated, lined both sides with HARDIES 6mm villa board, painted.				0.4	31		$150/m2	
Mineral fibre ceiling tiles in exposed suspension grid								
Φ 100 down pipe		2			6	12		

LVL structural member	location	no	hrs/no	crane operator	labour	crane cost	labour rate	Total
Column	C1,2,3,4,5,6	6	0.5	1	2	$ 200.00	$ 80.00	$ 1,320.00
walls and edge beams		2	2	1	2	$ 200.00	$ 80.00	$ 1,760.00
Beam		9	0.25	1	2	$ 200.00	$ 80.00	$ 990.00
TCC floor units		10	0.65	1	2	$ 200.00	$ 80.00	$ 2,860.00